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Coastal and Hydraulics Laboratory

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Typhoon-Induced Stage-Frequency Relationships for the Island of Rota, Commonwealth of the Northern Mariana Islands

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ABSTRACT:

A set of typhoon-induced stage-frequency relationships was developed for inhabited coasts of the island of Rota, Commonwealth of the Northern Mariana Islands. The objective was to assist the Honolulu District in estimating extreme maximum inundation levels and maximum still-water levels with return period of up to 500 years. Calculations of surge, wind and pressure field, and wave characteristics were performed for 28 historical storms and four hypothetical variations of historical storms through application of numerical models. Wave-induced ponding, setup, and runup were calculated at 87 profile locations specified by the Honolulu District. The Empirical Simulation Technique was applied to calculate stage-frequency relationships based on historical storm parameters and calculated response to the storms. These relationships were calculated from the maximum total water levels computed for each storm (including storm surge, ponding, and runup) and from the maximum still-water levels for each storm (including storm surge, ponding, and wave setup). The methodology was calibrated to observations so that stage-frequency values for maximum total water level are expected to represent maximum debris line inundation levels.

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Preface

This report describes the procedures and results of a typhoon stage-frequency analysis for coastal study areas along the island of Rota, Commonwealth of the Northern Mariana Islands. The study was performed by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), for the U.S. Army Engineer District, Honolulu. The study was conducted during the period January 1999 through May 2003. Mr. Steven H. Yamamoto, Honolulu District, was the study manager and point of contact.

The investigation reported herein was conducted by Dr. Edward F. Thompson of the Coastal Harbors and Structures Branch (CHSB), CHL, and Dr. Norman W. Scheffner, of the Estuarine Engineering Branch (EEB), CHL. Mr. David J. Mark, EEB, helped guide critical phases of the tide and storm surge modeling and overall study.

This study was performed under the general supervision of Mr. Thomas W. Richardson, Director, CHL. Direct supervision of this project was provided by Mr. Dennis Markle, Chief, CHSB.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL James R. Rowan, EN, was Commander and Executive Director.

1 Introduction

The island of Rota is located in the western Pacific Ocean at long. 145.2° E and lat. 14.2° N. Rota lies approximately midway between Japan and the northern tip of Australia (Figure 1). Rota is one of the Mariana Islands, an island chain at the southern end of a volcanic ridge stretching south from the Japanese island of Honshu. The island of Guam anchors the southern end of the chain. Rota lies 76 km (47 miles) north of Guam. The Mariana Trench, a deep rift in the ocean floor, wraps around Guam to the south and east and approximately parallels the northern Mariana Islands. The Mariana Island chain divides the Pacific Ocean on the east from the Philippine Sea on the west.

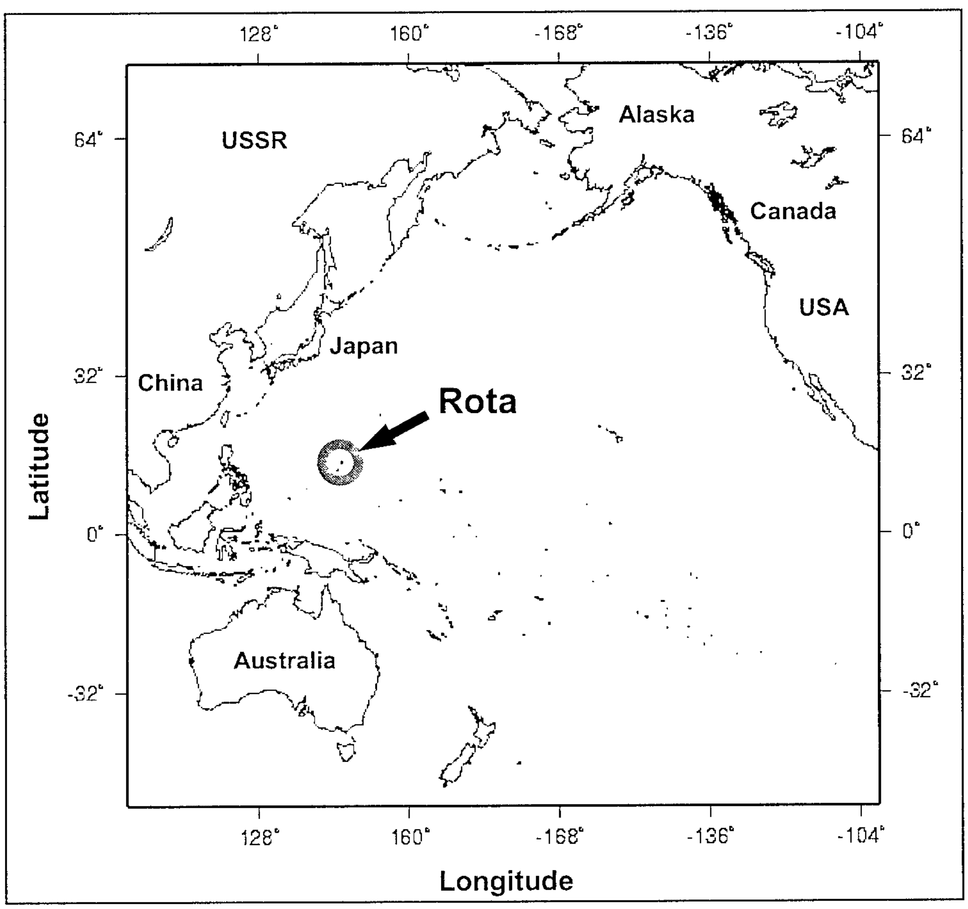

Figure 1. Vicinity map

Politically, Rota is part of the Commonwealth of the Northern Mariana Islands (CNMI). The CNMI consists of 14 volcanic islands, with most of the population located on Saipan, 117 km (73 miles) north of Rota. Approximately 3,500 people inhabit Rota, and the island offers some tourist attractions and facilities. Rota is affiliated with the United States as a result of a trusteeship agreement established in the aftermath of World War II. The trusteeship agreement eventually matured into commonwealth status for Rota and the other northern Mariana Islands.

The island of Rota is approximately17 km (10.5 miles) long and 5 km (3 miles) wide (Figure 2). It covers an area of 85 sq km (33 square miles). Most of the population resides in the island's western half. The principal community lies at the landward end of the tail-like Taipingot peninsula at the island's western tip. Most coastal shelf and beach areas are narrow, often with steep, rugged terrain inland of the coast, as is typical for volcanic islands. Fringing coral reefs are common around the island. Water depth over the reefs is very shallow and some reef areas are exposed at low tide. Thus, the reefs provide an important measure of natural protection to coastal areas from damaging waves.

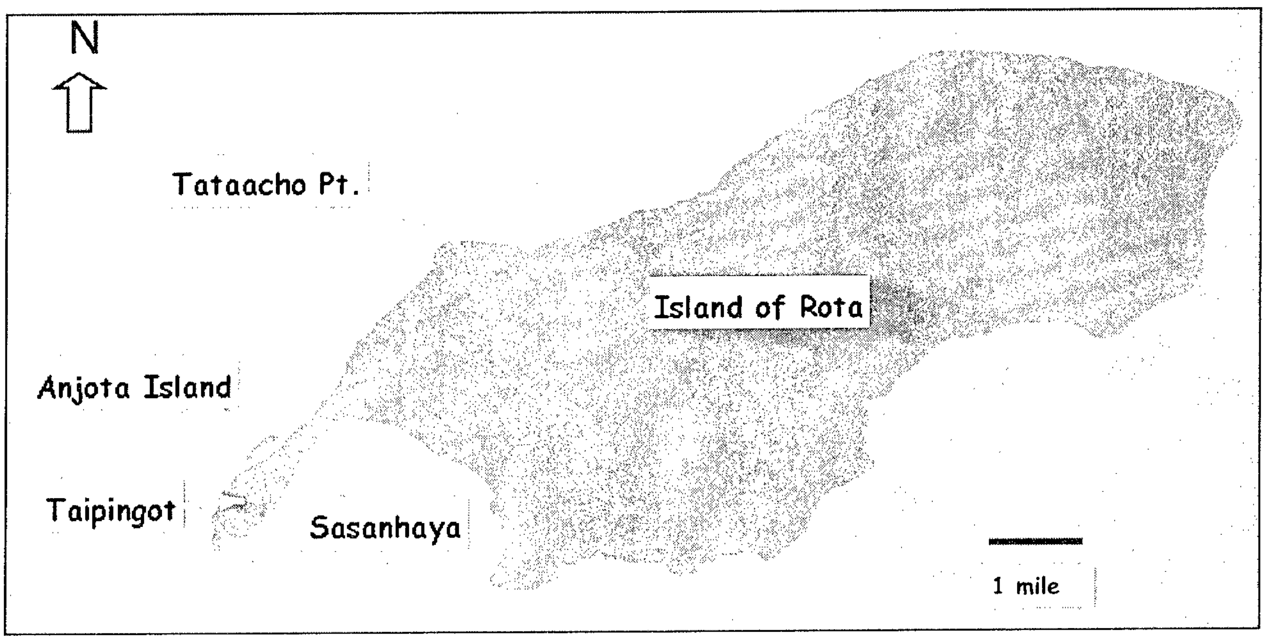

Figure 2. Location map, island of Rota

Rota's low-latitude location is favorable for tropical storm and typhoon formation and passage. The island often experiences typhoon impacts and occasionally a typhoon passes directly over the island. Typical typhoon impacts include wind and rainfall damage to buildings, roads, and crops; and coastal damage due to high waves and water levels. For example, in November and December 1997, two super typhoons (Keith and Paka) brushed across Rota in close succession, causing major damage.

In support of its mission, the U.S. Federal Emergency Management Agency (FEMA) funded the U.S. Army Engineer District, Honolulu, to conduct a flood insurance study for the island of Rota. The Honolulu District funded the

U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (CHL), to analyze typhoon-induced coastal inundation to assist in delineating flood-prone areas. CHL's study task was to calculate stage-frequency relationships for representative shore-perpendicular transects in the study area. This report documents procedures and results from the CHL study. The study area consists of two stretches of coast encompassing the vulnerable population and road areas of the island (Figure 3). One stretch is located inside Sasanhaya embayment, covering a 3.4-km (2.1-mile) length of coast. The other stretch extends from the west side of Taipingot peninsula up to Tataacho Point and then continues east and northeast to a mid-island longitude where the coastal road turns inland. This stretch is 10.9 km (6.8 miles) long.

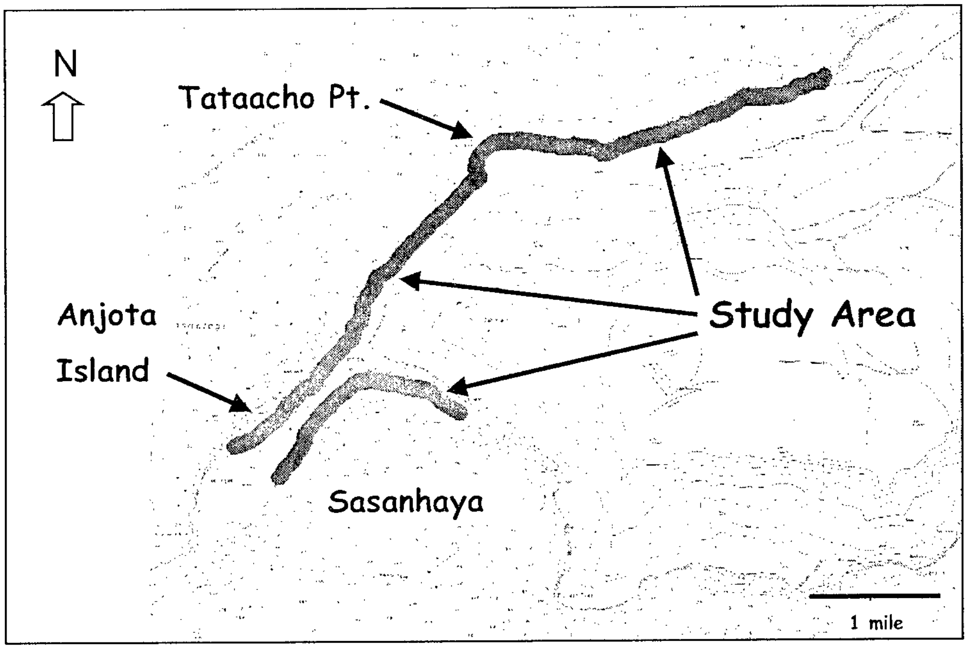

Figure 3. Study area

This report describes the procedures and results of the typhoon stage-frequency analysis for the study area coastline of Rota. Many of the techniques employed in this study have been successfully applied in previous stage-frequency analyses (Mark 1996; Mark and Scheffner 1997; Militello, Scheffner, and Thompson 2003). Another closely related CHL study evaluated overtopping rates rather than water levels along an exposed coast adjacent to the commercial port road at Apra Harbor, Guam (Thompson and Scheffner 2002). Because Apra Harbor and Rota are relatively close geographically and the time frame for the two studies coincided, some efforts benefitted both studies and helped reduce study costs.

The analysis for this study consisted of five tasks. The first task was development of a typhoon database for the western Pacific Ocean and analysis of storm statistics and correlations. Storms impacting the study area were selected from the database to create a smaller, representative group of storms called the training set. A planetary boundary layer model was applied to calculate wind and atmospheric pressure fields for each storm in the training set.

The second task consisted of simulation of storm surge by application of a long-wave, finite-element hydrodynamic model. For each storm in the training set, storm surge was calculated at selected sites in the study area. The third task consisted of wave parameter calculation for each storm by application of a wave growth/propagation model and a nearshore wave-transformation model. The fourth task consisted of time-series calculation of ponding level, setup, and runup for each storm. These calculations were performed for profiles specified by the Honolulu District.

The fifth task was the development of frequency-of-occurrence relationships for water levels along the study coasts. These relationships were developed by application of the Empirical Simulation Technique (EST) to relate typhoon parameters and corresponding storm water levels. The EST is a statistical resampling procedure that applies historical data to develop joint probability relationships among the various measured storm parameters (e.g., maximum wind speed). The resampling scheme generates large populations of data that are statistically similar to a much smaller database of historical events, i.e. the training set of storms. Application of the EST to the expanded storm set produces a database of peak water levels by repeatedly simulating multiple-year periods (e.g., 200-year periods) of storm activity. Expected stage-frequency relationships are then calculated from the database of peak storm-induced water levels. Because of the repeated simulations, a measure of expected variability of calculated stage-frequency relationships is also provided.

This report is divided into six chapters. Following the introduction, Chapter 2 describes selection of storms to be modeled. Chapter 3 describes key models and methods used in the study including meteorological, wave, and long-wave hydrodynamic models, nearshore analysis, and EST. Chapter 4 discusses long-wave hydrodynamic model calibration, validation, and implementation. Chapter 5 reviews the methods as applied in this study for calculation of stage-frequency relationships and presents study results. Chapter 6 provides summary and conclusions of the study. References are listed after Chapter 6.

Appendices follow the main report. Appendix A shows tracks followed by typhoons selected for modeling. Appendix B contains a listing of station locations for storm surge calculations. Corresponding topographic profile numbers are given in Appendix C. Appendices D and E give stage-frequency relationship tables and plots, respectively. Appendix F contains tables of wave parameters, peak water levels, and water level components corresponding to peak water level in each modeled storm for selected profiles.

2 Storm Selection

This chapter describes typhoons selected for modeling and the procedures used for selection. The objective was to develop a set of approximately 30 typhoons which are representative of storms affecting flooding along the study area coasts of Rota. Coincidental, a similar study of flooding along a coast of Apra Harbor, Guam, was ongoing at the time of this study (Thompson and Scheffner 2002). The two islands are sufficiently close together that they are affected by the same storms. One historical storm data set served the needs of both studies.

The database of historical typhoons in the western Pacific is available on the internet through the U.S. Navy's Joint Typhoon Warning Center (JTWC), *http://www.npmoc.navy.mil/products/jtwc/best_tracks*. Typhoon track data covering the years 1945-97 were used. Track data are given at 6-hour intervals, including latitude and longitude of the storm eye (with 0.1-deg precision) and maximum sustained 1-min mean surface wind, in knots. Western Pacific storms are identified with prefix *BWP* followed by a four-digit number: the first two digits give sequential storm number for the year (01 is the first western Pacific storm for the year, etc.) and the second two digits give the year. For example, Typhoon Pamela (BWP0676) was the sixth western Pacific typhoon during the year 1976. These four-digit numbers are used as storm identifiers in the present study. Tropical storms originating outside the western Pacific which may affect the study area have other prefix identifiers. These other possibilities were considered, but the only such storm important in this study was Paka (BCP0597), indicating it originated in the central Pacific.

Available information about storm impacts on Rota and Guam was also gathered and reviewed to insure the storm selection process included all important historical storm events. Sources included JTWC (1991) and JTWC annual and special storm reports. This review resulted in elimination of one typhoon (Querida 1246) from consideration because the best track data differed significantly from the published description of storm track relative to Guam and Rota. Subsequent discussions with JTWC indicated that storms from before 1959 in the present data set should be considered less reliable. Other than Querida, pre-1959 storms were retained for modeling consideration because there were no inconsistencies evident in the best track files and it was desirable to preserve the full 53-year historical database.

Only typhoons that passed within a 322-km (200-mile) square box centered on the islands of Rota and Guam and had wind speeds of 64 knots (typhoon strength) or greater within the box were considered. From these typhoons, the following considerations were applied to select a storm set for modeling. Tracks for the selected typhoons are shown in Appendix A.

Strong and weak typhoon pairs. Typhoons typically approach Rota from the east, continue moving toward the west past the island, and eventually curve toward the northwest. A small number of typhoons have approached from the south and continued moving northward past the island. Historical typhoons have no evident preference for passing on one particular side of the island and occasionally they pass directly across the island. A representative set of six strong and weak typhoon pairs (12 storms) was selected for the following cases, based on analysis of the types of tracks and storms:

a. West-moving, far north of islands.

b. West-moving, near north of islands.

c. West-moving, near south of islands.

d. West-moving, far south of islands.

e. North-moving, west of islands.

f. North-moving, east of islands.

Typhoons passing near islands. All remaining typhoons that passed close to the islands (basically between Rota and Guam or across either island) were selected, a total of 14 storms. These storms were considered potentially damaging because of their proximity to Rota.

Additional typhoons. The preceding criteria give a relatively complete and representative set of historical storms affecting Rota. Several other typhoons, not chosen initially by the criteria, were also reviewed to insure that all historically damaging storms were considered. These included three other candidate strong storms for "West-moving, far north of islands," and a few other typhoons with unusual tracks and some potential for generating wave and flooding impacts on Rota and/or Apra Harbor. JTWC annual reports and storm reports were consulted to see if any of these storms caused notable wave and flooding damage. Based on these considerations, two additional typhoons were added to the model set, giving a total of 28 storms.

Extreme typhoons. The impact of a typhoon on the study area at Rota can be strongly affected by typhoon track. Historical data provide a valuable record, but storms with small variations in the historical tracks would have been equally likely. For analysis of extremes, it is important to capture small variations in the most damaging storms that would have caused them to be more damaging to the study area. These are referred to as hypothetical storms.

Two historical storms were considered with altered tracks to develop hypothetical cases to complete the storm data set: Gilda (3367) and Olive (0163). Gilda's historical track past Rota was toward west northwest, with the eye slicing directly across the island's midsection. Olive's historical track was west of Guam and Rota, moving toward the north with a slight curve toward northeast. Several hypothetical variations in Gilda were studied, with track shifted slightly north and south of the actual track. Gilda with track shifted north by 20 km (12.7 miles) created larger waves offshore from some of the study area coasts than the historical Gilda or any other historical typhoon modeled. Thus, a hypothetical typhoon consisting of Gilda with track shifted 20 km (12.7 miles) north was added to the model set.

Olive with track shifted 0.67 deg toward the east swept through Sasanhaya embayment and across Rota and had a major impact on offshore waves approaching that study area. It was added to the storm set for modeling.

For statistical balance in the modeled storm set, two additional hypothetical typhoons were added to the model set, representing Gilda with track shifted 20 km (12.7 miles) south and Olive with track shifted 0.67 deg to the west. In the EST analysis, each storm in a trio of hypothetical storms and associated historical storm is given one-third the weighting of other historical storms to preserve the historical frequency-of-occurrence statistics.

With the addition of two hypothetical storms and their shifted tracks, the final data set for modeling contained a total of 32 storms. The storms are listed in Table 1. Storm numbers used for hypothetical storms are similar to the historical storm number on which they are based, but the first digit is changed as a key identifying the hypothetical variation.

Statistical Representativeness. Typhoons selected for modeling should be fairly representative of storm track statistics for the full set of typhoons passing into the box around Rota and Guam. Typhoons were classified according to their travel direction, and results are given in Table 2. Hypothetical storms are not included in these statistics. The storms selected for modeling are considered sufficiently representative of the full set of storms.

Table 1
Typhoons Selected for Modeling, Island of Rota

Number	Name	Inclusive Dates
BWP2348	Agnes	11/13/48 – 11/19/48
BWP0150	Doris	05/07/50 – 05/13/50
BWP0853	Nina	08/09/53 – 08/17/53
BWP1953	Alice	10/12/53 – 10/19/53
BWP1557	Hester	10/04/57 – 10/10/57
BWP2057	Lola	11/08/57 – 11/21/57
BWP1861	Nancy	09/08/61 – 09/16/61
BWP2762	Karen	11/08/62 – 11/16/62
BWP0163	Olive	04/27/63 – 05/05/63
BWP2563	Susan	12/19/63 – 12/28/63
BWP2965	Bess	09/27/65 – 10/05/65
BWP3367	Gilda	11/09/67 – 11/18/67
BWP2168	Irma	10/20/68 – 10/24/68
BWP0571	Amy	04/30/71 – 05/06/71
BWP0676	Pamela	05/14/76 – 05/28/76
BWP1977	Kim	11/07/77 – 11/16/77
BWP2379	Tip	10/04/79 – 10/19/79
BWP2187	Lynn	10/15/87 – 10/27/87
BWP0188	Roy	01/06/88 – 01/17/88
BWP0289	Andy	04/13/89 – 04/24/89
BWP0190	Koryn	01/08/90 – 01/17/90
BWP3190	Russ	12/13/90 – 12/24/90
BWP2691	Seth	10/29/91 – 11/14/91
BWP1592	Omar	08/20/92 – 09/06/92
BWP3192	Gay	11/14/92 – 11/30/92
BWP3594	Wilda	10/18/94 – 11/01/94
BCP0597	Paka	12/08/97 – 12/21/97
BWP2997	Keith	10/23/97 – 11/09/97
1367	Hypothetical	Gilda BWP3367 with track shifted north 20 km (12.7 miles)
4367	Hypothetical	Gilda BWP3367 with track shifted south 20 km (12.7 miles)
5163	Hypothetical	Olive BWP0163 with track shifted east 0.67 deg
6163	Hypothetical	Olive BWP0163 with track shifted west 0.67 deg

Table 2
Statistics of Typhoon Travel Direction

Travel Direction	Full Set of Storms		Storms Selected for Modeling	
	Number of Storms	Percent	Number of Storms	Percent
Moving toward west	75	65	18	64
Moving toward north	27	23	6	21
Moving toward west & then north	11	9	3	11
Moving toward east	3	3	1	4
Total	116	100	28	100

3 Modeling Approach

Calculation of typhoon stage-frequency relationships for study area coasts along the island of Rota requires application of several standard CHL numerical models and many additional processing steps. The objective of this chapter is to explain the modeling approach and document models and procedures used in the study. An overview of the modeling approach is given in the following paragraphs. More detailed descriptions of key modeling steps are given in following sections of the chapter.

The main modeling steps are as follows. First, a Planetary Boundary Layer (PBL) wind model simulates the time-history of typhoon-induced wind and atmospheric pressure fields for each selected storm during its general proximity to the study area. The time-history of wind information serves as input to both a long-wave hydrodynamic model ADCIRC and a wind-wave model WISWAVE. The ADCIRC model provides a refined time-history of typhoon-induced water levels at the study location for each storm. The WISWAVE model provides a time-history of deepwater wave parameters in the general vicinity of Rota coasts.

For the study areas, including the south-facing Sasanhaya embayment coast and the northwest- and west-facing exposed coasts, WISWAVE information from an appropriate offshore grid point is adjusted to provide a time-history of waves incident to the nearshore coral reef. The adjustment is done with the wave-transformation model WAVTRAN. These wave parameters are subsequently matched in time with nearshore water level information from ADCIRC and used to calculate a time-history of wave ponding over the reef and nearshore setup and runup. Maximum water level is extracted for each nearshore profile in each storm. The EST analysis is applied and water levels are calculated for various return periods.

Wind and Atmospheric Pressure Field Model

The PBL numerical model was used for simulation of typhoon-generated wind and atmospheric pressure fields. The model applies vertically averaged primitive equations of motion for predicting tropical storm wind velocities. The model includes parameterization of momentum, heat, and moisture fluxes together with surface drag and roughness formulations. Through hindcast applications, Cardone, Greenwood, and Greenwood (1992) found that the PBL model calculates accurate surface wind speeds and directions as compared to measurements collected in tropical storms over open water.

The PBL model requires a set of storm parameter snapshots for input. The snapshots consist of meteorological storm parameters that define the storm at various stages in its development or at particular times during its life. These parameters include: latitude and longitude of the storm's eye; track direction and forward speed measured at the eye; radius to maximum winds; central and peripheral atmospheric pressures; and an estimate of the geostrophic wind speed and direction. Also, the direction and speed of steering currents can be provided for representing asymmetric storms.

Storm tracks and maximum sustained 1-min mean surface winds were obtained from the JTWC database described in Chapter 2. Information contained in this database is provided at 0000, 0600, 1200, and 1800 hr Greenwich Mean Time (GMT). The JTWC storm files were preprocessed to put them into the required snapshot format and to estimate other necessary parameters. Central pressure was calculated from maximum sustained 1-min mean surface wind speed using the relationship developed by Atkinson and Holliday (1977), based on data from Guam

$$W = 6.7\left(P_a - P_c\right)^{0.644} \tag{1}$$

where

W = maximum sustained 1-min mean surface wind speed in knots

P_a = ambient pressure in mb

P_c = central pressure in mb

Ambient pressure is taken to be 1,010 mb, in accordance with Atkinson and Holliday's (1977) recommendation for the western North Pacific area.

Radius to maximum winds (RMW) is approximated by application of relationships developed in a generalized numerical model study of storm characteristics (Jelesnianski and Taylor 1973). The RMW is based on W and the central pressure deficit, P_a - P_c. Track directions and forward speeds required by the PBL model are approximated by cubic spline interpolation at hourly intervals from 6-hr coordinate positions provided in the database. Geostrophic wind speeds were specified as 6 m/s.

The spatial area covered by a tropical storm at a given time is specified in the PBL model to correspond to a set of nodes on a numerical grid. Wind velocities and atmospheric pressure values are computed at each node in the grid. Whereas some models employ a fixed grid system to simulate a tropical storm (i.e., stationary grid with a moving storm), the PBL model simulates a typhoon as a stationary storm with a moving grid. Forward motion of the storm is calculated as the vector sum of the forward and rotational velocity vector components. The numerical grid is moved with the storm at the calculated forward velocity at each time-step so that the grid center always coincides with the storm center.

The distribution of wind speed and radial change in wind speed varies spatially within a tropical storm such that higher spatial resolution of the wind field is required in the central region of the storm, whereas coarser resolution suffices on the outer areas. To provide spatially-graded resolution of the wind field, a nested gridding technique is applied consisting of five layers or subgrids. The grid nesting is applied such that all subgrids contain the same number of nodes, however, the spatial coverage and resolution differs and is successively graded. Each subgrid is composed of 21 by 21 nodes in the x- and y-directions, respectively. The centers of all subgrids lie on node (11,11), defined at the eye of the tropical storm. For this study, the subgrid with the finest resolution had an incremental distance of 5 km (3.1 miles) between nodes and covered an area of 10,000 sq km (3,861 square miles). Incremental distances for the remaining subgrids were 10, 20, 40, and 80 km (6.2, 12.4, 24.9, and 49.7 miles) and their areas of coverage were 40,000, 160,000, 640,000, and 2,560,000 sq km (15,444, 61,776, 247,104, and 988,428 square miles), respectively.

For each snapshot, the equations of motion are first solved for the subgrid covering the greatest area. Computed wind velocities are then applied as boundary conditions on the second-largest grid, and the equations are solved again. This procedure is followed for the remaining grids where wind fields are computed on successively smaller grids. Thus, the nested grid technique provides wind field information over a wide spatial area while sufficient grid resolution is provided to accurately compute winds in the vicinity of the tropical storm eye.

After all snapshots have been processed, hourly wind and atmospheric pressure fields are interpolated using a nonlinear blending algorithm which produces a smooth transition from one snapshot to the next. Hourly wind and pressure fields are then interpolated from the PBL grid onto the hydrodynamic or wave model grid and subsequently stored for use by those models. Wind velocities produced by the PBL model represent an averaging time of 30-60 min, which is appropriate for wave and storm surge modeling (Thompson and Cardone 1996).

Storm Surge Model

The ADvanced CIRCulation (ADCIRC) numerical model was applied for simulation of long-wave hydrodynamic processes in the study area. The model calculates a two-dimensional (2-D), depth-integrated finite-element solution of the Generalized Wave-Continuity Equation (GWCE). Fundamental components of the GWCE are the depth-integrated continuity and Navier-Stokes equations for conservation of mass and momentum. The assumption of incompressibility and the Boussinesq and hydrostatic pressure approximations were applied. The primitive, nonconservative form of the governing equations, given in spherical coordinates, as applied in the model are (Flather 1988; Kolar et al. 1993)

$$\frac{\partial \zeta}{\partial t} + \frac{1}{R\cos(\phi)}\left[\frac{\partial UD}{\partial \varphi} + \frac{\partial (UV\cos(\phi))}{\partial \phi}\right] = 0 \tag{2}$$

$$\frac{\partial U}{\partial t}+\frac{1}{R\cos(\phi)}U\frac{\partial U}{\partial \varphi}+\frac{1}{R}V\frac{\partial U}{\partial \phi}-\left[\frac{\tan(\phi)}{R}U+f\right]V$$
$$=-\frac{1}{R\cos(\phi)}\frac{\partial}{\partial \varphi}\left[\frac{P_S}{\rho_0}+g(\zeta-\alpha\xi)\right]+\frac{\tau_{S\varphi}}{\rho_0 D}-\tau_* U \tag{3}$$

$$\frac{\partial V}{\partial t}+\frac{1}{R\cos(\phi)}U\frac{\partial V}{\partial \varphi}+\frac{1}{R}V\frac{\partial V}{\partial \phi}-\left[\frac{\tan(\phi)}{R}U+f\right]U$$
$$=-\frac{1}{R\cos(\phi)}\frac{\partial}{\partial \phi}\left[\frac{P_S}{\rho_0}+g(\zeta-\alpha\xi)\right]+\frac{\tau_{S\phi}}{\rho_0 D}-\tau_* V \tag{4}$$

where

t = time

φ = degrees longitude (east of Greenwich is taken positive)

ϕ = degrees latitude (north of the equator is taken positive)

ζ = free-surface elevation relative to the geoid

U = depth-averaged velocity component parallel to the east-west axis

V = depth-averaged velocity component parallel to the north-south axis

R = radius of the earth

$D=\zeta+h$ = total water-column depth, h is the bathymetric depth relative to the geoid

$f=2\Omega\sin(\phi)$ = Coriolis parameter, Ω is the angular speed of the earth's rotation

P_S = atmospheric pressure at the free surface

g = acceleration due to gravity

$\alpha\xi$ = effective Newtonian equilibrium tide potential

ρ_0 = reference density of water

$\tau_{S\varphi}$ and $\tau_{S\phi}$ = applied free-surface stresses

τ_* = bottom stress given by $C_f\left(U^2+V^2\right)^{1/2}/D$ where C_f is the bottom-friction coefficient

The time-differentiated form of the conservation of mass equation is combined with a space-differentiated form of the conservation of momentum equation to develop the GWCE (Westerink et al. 1992) given by

$$
\begin{aligned}
&\frac{\partial^2\zeta}{\partial t^2}+\tau_0\frac{\partial\zeta}{\partial t}-\frac{1}{R\cos(\phi)}\frac{\partial}{\partial\varphi}\left\{\frac{1}{R\cos(\phi)}\left[\frac{\partial(DUU)}{\partial\varphi}+\frac{\partial(DUV\cos(\phi))}{\partial\phi}\right]-UVD\frac{\tan(\phi)}{R}\right\} \\
&\left\{-2\Omega\sin(\phi)DV+\frac{D}{R\cos(\phi)}\frac{\partial}{\partial\varphi}\left[g(\zeta-\alpha\xi)+\frac{P_S}{\rho_0}\right]+\tau_* DU-\tau_0 DU-\frac{\tau_{S\varphi}}{\rho_0}\right\} \\
&-\frac{1}{R}\frac{\partial}{\partial\phi}\left\{\frac{1}{R\cos(\phi)}\left[\frac{\partial DVV}{\partial\varphi}+\frac{\partial DVV\cos(\phi)}{\partial\phi}\right]+UUD\frac{\tan(\phi)}{R}+2\Omega\sin(\phi)DU\right\} \\
&-\frac{1}{R}\frac{\partial}{\partial\phi}\left\{\frac{D}{R}\frac{\partial}{\partial\phi}\left[g(\zeta-\alpha\xi)+\frac{P_S}{\rho_0}\right]+(\tau_*-\tau_0)DV-\frac{\tau_{S\phi}}{\rho_0}\right\} \\
&-\frac{\partial}{\partial t}\left[\frac{VD}{R}\tan(\phi)\right]-\tau_0\left[\frac{VD}{R}\tan(\phi)\right]=0
\end{aligned}
\qquad (5)
$$

The coefficient τ_0 represents a GWCE weighting function that permits solution behavior to have characteristics between those of the primitive equation and the pure wave equation. The ADCIRC model solves the GWCE (Equation 5) in conjunction with the primitive momentum equations given by Equations 3 and 4.

The GWCE-based solution scheme eliminates several problems associated with finite-element models that solve the primitive forms of the continuity and momentum equations (i.e., Navier-Stokes equations), including spurious modes of oscillation and artificial damping of the tidal signal. Forcing functions include time-varying water-surface elevation, wind stress, atmospheric pressure, and the Coriolis effect.

The computational grid developed for this study is a large-domain circular grid with a radius of 4 deg (276 miles) and center at long. 145° E and lat. 14° N. The islands of Rota and Guam are located in the central region of the grid. The large scale of the grid has two main advantages. First, the tidal forcing boundaries are far from the region of interest such that island shorelines are free from boundary effects. Second, because typhoons are large-scale atmospheric phenomena, a large-domain grid is preferred to maximize the interaction of the horizontal storm area with the computational grid, as well as the storm track.

The grid developed for this study is shown in Figure 4. Grid resolution is coarser in the open regions with increasing resolution toward the shore. Grid parameters and range of scale of element sizes contained in the grid are given in Table 3. Two Mariana Islands north of Rota were sufficiently large and close that they are included in the grid: Saipan and Tinian. The grid around these islands was specified to be much coarser than the region surrounding Rota. Grid resolution around Guam was also relatively coarse in comparison to the recent Apra Harbor study (Thompson and Scheffner 2002).

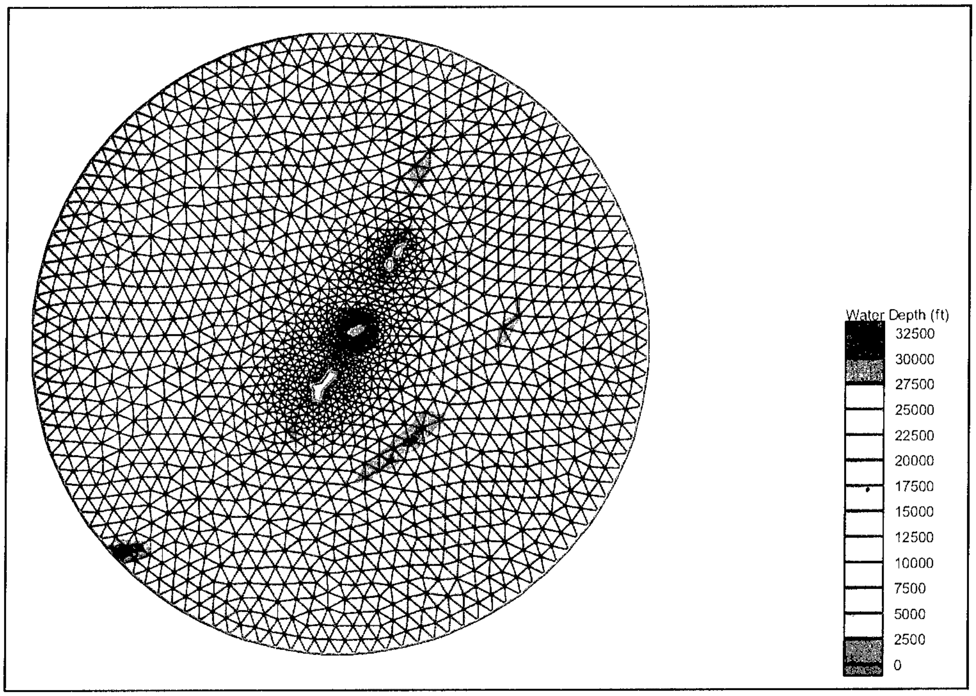

Figure 4. Complete computational grid for Rota study

Table 3
Storm Surge Grid Parameters

Parameter	Value
Maximum element area	462,087,758 m^2 (4,973,750,272 ft^2)
Minimum element area	3,112 m^2 (33,494 ft^2)
Ratio of maximum to minimum element areas	148,497
Number of elements	7,983
Number of nodes	4,315
Center longitude and latitude	145 E, 14 N
Circular grid radius	4 deg

The finest grid resolution is around the study area. Reefs, shallow areas, and embayments are finely resolved in and near the study area so that the hydrodynamics can be accurately calculated in these regions. Details of the grid around Rota are shown in Figure 5. Figure 6 shows detail of the study area. Because of the fine grid resolution in reef areas coupled with the extreme hydrodynamic conditions (strong currents and rapid change in water level) associated with the storms, a time-step of 5 sec was required for model runs.

Several data sources were accessed for development of the computational grid. Initially, shoreline and bathymetry data were obtained from the U.S. Department of Defense Digital Nautical Chart database (National Imagery and Mapping Agency (NIMA) 1999). The digital database was supplemented in offshore areas by digitizing points and contours from National Oceanic and Atmospheric Administration (NOAA) Chart #81004 and DMA Chart #81025 as needed to get a complete representation. The Rota island boundary and coastal bathymetry, which were absent from the NIMA database, were digitized from

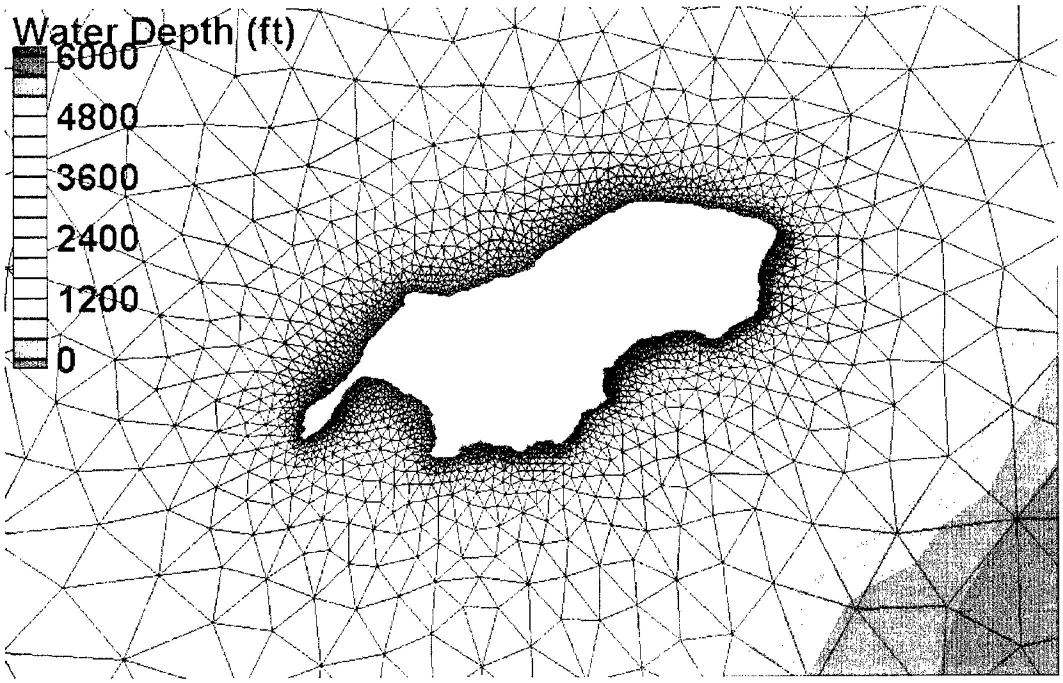

Figure 5. Computational grid showing detail for Rota

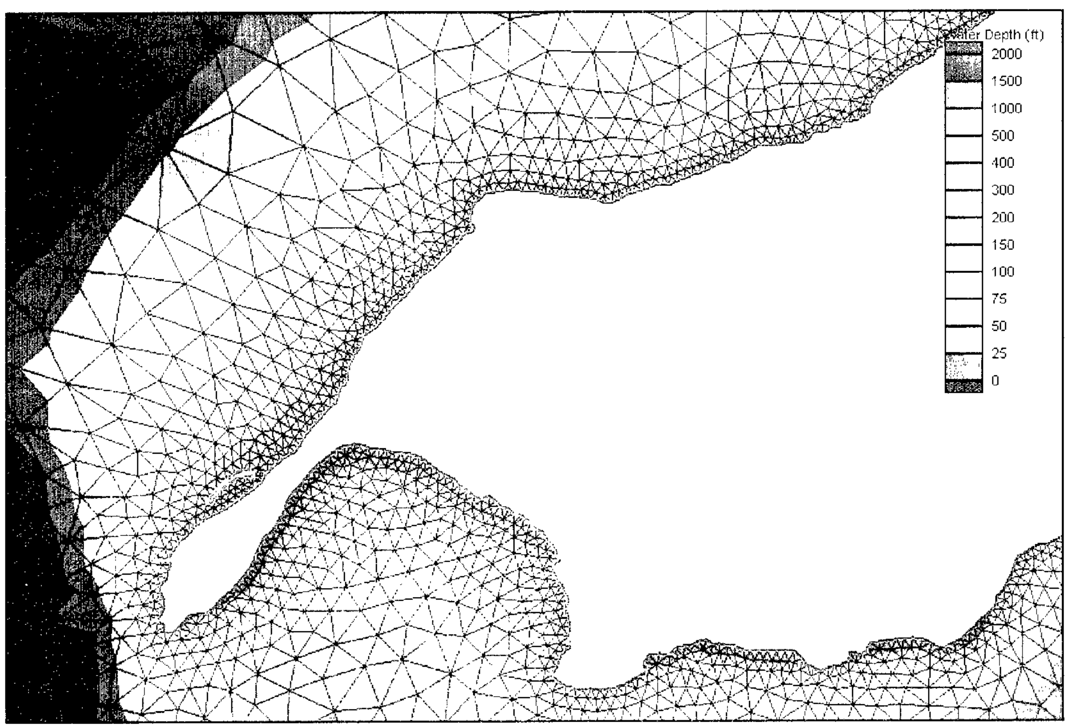

Figure 6. Computational grid showing detail for study area

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NOAA Chart #81063. Bathymetry around Guam was supplemented using NOAA Chart #81048. Grid depths are referenced to mean sea level (msl).

Tidal elevations specified at the open-water boundary were calculated from tidal amplitudes and phases contained in the LeProvost World Tidal Constituent Database, which provides constituent data at 1-deg increments in latitude and longitude. A bilinear interpolation algorithm was applied to calculate tidal amplitudes and phases at 118 open boundary nodes. The six tidal constituents applied at the open boundaries were: M_2, S_2, N_2, P_1, O_1, and K_1.

Wave and Wave Transformation Models

Deepwater wave fields were calculated by application of the Wave Information Studies Wave (WISWAVE) model (Hubertz 1992; Resio and Perrie 1989). This model is a second-generation discrete directional spectral wave model in which the spectral wave computations are based on the integration of energy over the discrete frequency spectrum. Model output includes time series of significant wave height, peak (dominant) or mean wave period, and mean wave direction. Peak period is defined as the period associated with the mid-band frequency, or that frequency band containing the largest spectral energy density. Mean wave period is an energy-weighted quantity integrated over all user-specified frequencies of interest. Model input includes a rectilinear computational grid, with water depths specified at each node, and wind speed and direction over the grid domain.

Application of the wave model required a grid resolution such that calculation points could be distributed around and near to the coasts of Rota and Guam so that representative wave conditions would be captured for all sides of the islands needed in the studies. To meet this requirement, a grid with constant spacing of 0.083 deg was developed. For wave modeling at this scale, deep water can be applied over the grid. The islands of Rota and Guam were specified as land in the grid for accurate calculation of wave sheltering and refraction. At this grid scale, Rota is represented by 6 land points and Guam by 22 land points. Details of the grid are given in Table 4.

Table 4
WISWAVE Grid Parameters

Parameter	Value
Longitude limits	141.0333 E , 149.0333 E
Latitude limits	10.0333 N, 18.0333 N
Cell side length	0.083 deg
Total number of nodes	9409
Number of nodes in north-south direction	97
Number of nodes in east-west direction	97

Wind forcing for the wave model was calculated by application of the PBL model, as discussed previously. Wind speed and direction were calculated for each point on the wave grid at 1-hr intervals.

Deepwater wave parameters calculated by the wave model were stored at 24 stations surrounding Rota and eight stations around Apra Harbor and the west coast of Guam for each of the 32 storms in the training set (described in Chapter 2). A list of these stations is given in Table 5. The deepwater wave stations are well offshore on a coarse grid pattern rather than the detailed storm surge grid pattern described previously. The duration of wave simulations corresponded to the time coverage of each storm in the JTWC database. Thus, each storm simulation began when the storm center was well outside the WISWAVE grid and ended with the storm cell well beyond the grid. Wave parameters were stored at 1-hr intervals.

Table 5
Deepwater Wave Stations

Station Number	Latitude, deg N	Longitude, deg E
1	13.37	144.45
2	13.45	144.45
3	13.53	144.45
4	13.45	144.53
5	13.53	144.53
6	13.62	144.53
7	13.53	144.62
8	13.62	144.62
9	14.12	144.95
10	14.20	144.95
11	14.03	145.03
12	14.12	145.03
13	14.20	145.03
14	14.28	145.03
15	13.95	145.12
16	14.03	145.12
17	14.28	145.12
18	14.37	145.12
19	13.95	145.20
20	14.03	145.20
21	14.28	145.20
22	14.37	145.20
23	13.95	145.28
24	14.03	145.28
25	14.28	145.28
26	14.37	145.28
27	14.03	145.37
28	14.12	145.37
29	14.20	145.37
30	14.28	145.37
31	14.12	145.45
32	14.20	145.45

Deepwater waves produced by WISWAVE were transformed to the study area by application of the nearshore wave transformation model WAVTRAN (Jensen 1983; Gravens, Kraus, and Hanson 1991). The WAVTRAN model calculates spectral transformation of waves during propagation from one depth to another shallower depth, taking into account shoreline orientation and wave sheltering. The model assumes that sea and swell waves have an energy spectrum that follows the Texel, MARSEN, ARSLOE (TMA) spectral form (Bouws et al. 1985). Directional spread is calculated by 4th and 8th power cosine functions. Wave transformation calculation is dependent on the shoreline orientation because bottom contours are assumed parallel to the shoreline. If wave sheltering is included, wave energy coming from directions specified by a sheltered angle band are deleted from the spectrum. Typically, sheltering is applied as needed to remove wave energy from any direction which is blocked from a straight-line approach to the site by protruding land forms. Details of the model application for this study are given in Chapter 5.

Wave Ponding on Reefs

Wave-forced impoundment of water over reefs, often called wave ponding, is caused by overtopping and breaking of waves onto the reef platform. As waves overtop and break on the reef, water is collected over the reef causing an elevated water level across the full width of the reef (Figure 7). Seelig (1983) conducted a set of laboratory flume experiments for fringing reef profiles typical of Guam to investigate hydraulics of reef-lagoon systems. Wave ponding level resulting from wave overtopping and breaking was included in the study. Parameter ranges were varied as follows: still-water depth at the reef crest was specified to be 0 m (0 ft) and 2 m (6.6 ft), wave periods ranged from 8 to 16 sec, and irregular deepwater significant wave height ranged from 2.5 to 10.7 m (8.2 to 35.1 ft).

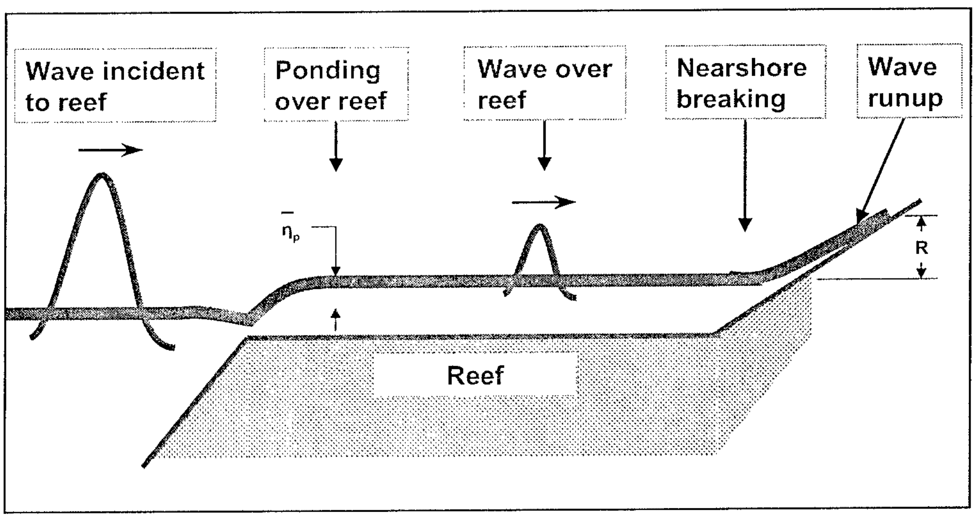

Figure 7. Definition sketch of wave ponding and runup

Seelig found that ponding water level is a function of still-water level (astronomical tide and storm surge), deepwater significant wave height, and wave period. Gourlay (1996) confirmed these findings. Ponding level varies with time, increasing when a group of several unusually high waves impacts the reef and decreasing during sequences of lower waves. Mean ponding level can be estimated by (Seelig 1983)

$$\overline{\eta}_p = a_1 + a_2 \log\left(H_0^2 T_p\right) \tag{6}$$

where

$\overline{\eta}_p$ = mean ponding level

H_0 = deepwater significant wave height incident to the reef face

T_p = peak wave period

a_1 and a_2 = empirical coefficients dependent on the still-water level

Table 6 gives values of the empirical coefficients for irregular waves when H_0 and $\overline{\eta}_p$ are expressed in meters.

Table 6
Ponding Level Coefficients for Irregular Waves (Seelig 1983)

Depth, m (ft)	a_1	a_2
0 (0)	-0.92	0.77
2 (6.6)	-1.25	0.73
Note: Depth measured relative to reef crest		

Wave Setup and Runup

Ponding is considered as an increase in water level over the full width of the reef, extending from the seaward edge of the reef flat to shore. An additional, localized, increase in water level at the shore is caused by final breaking of waves re-formed within the lagoon system after initial breaking on the reef. The localized increase at shore includes wave setup due to wave breaking on the nearshore slope and wave runup on land (Figure 7). Wave setup is affected by local bathymetry; runup is highly influenced by local bathymetry and topography. As with ponding, these processes are modeled along a one-dimensional profile representative of the nearshore bathymetry and topography at each study site.

Wave setup results when the pressure gradient of the sloping water surface (i.e., mean still-water depth) is in equilibrium with the cross-shore directed radiation stress, which represents the gradient of momentum of incoming waves in the shoreward direction:

$$\frac{d\overline{\eta}}{dx} = -\frac{1}{\rho g d}\frac{dS_{xx}}{dx} \tag{7}$$

where

$\overline{\eta}$ = mean still-water level, ρ is the water density, g is the acceleration due to gravity

S_{xx} = cross-shore component of the cross-shore directed radiation stress

d = depth

x = cross-shore distance

Under the assumption of linear wave theory, wave setup in the surf zone is

$$\frac{d\overline{\eta}}{dx} = -\frac{3}{16}\frac{1}{d+\overline{\eta}}\frac{d\left(H^2\right)}{dx} \tag{8}$$

where H is the wave height. A representative wave setup for irregular waves can be approximated with guidance from the *Coastal Engineering Manual* (Headquarters, U.S. Army Corps of Engineers, 2002), which is based on Equation 8 adapted to irregular waves.

Wave runup, R, is the maximum water-surface elevation caused by the uprush of water at shore from a breaking wave. The *Shore Protection Manual* (1984) provides guidance for estimating runup due to a wide range of incident wave conditions and smooth, uniform bottom slopes, based on extensive laboratory testing with regular waves. Wave setup effects are included in the runup estimates. A method for adapting the guidance to nonuniform slopes is also provided, based on the composite slope approach of Saville (1958). Guidance is included for runup reduction factors to account for effects of slope roughness and porosity.

Incident wave height for setup and runup calculations is determined from wave conditions incident to the seaward edge of the reef, water depth over the reef, and reef width. For a very wide reef, incident wave height for setup and runup calculations is assumed to be equal to the maximum breaking wave height that can be sustained over the reef estimated by

$$H_b = \gamma_b d_b \tag{9}$$

where

H_b = height of the breaking wave

d_b = water depth over the reef

γ_b = breaking depth index

The breaking depth index can range from 1.1 to 0.4 across reefs, with the smaller values tending to be reached across wide reefs (Gerritsen 1980; Hardy et al. 1990). A typical breaking depth index for regular waves on beaches has a value of 0.78, but this value is overly conservative for calculation of design significant wave heights landward of the reef edge (Smith 1993).

For high offshore wave conditions and narrow reefs, incident wave height for setup and runup calculations can be expected to be higher than the limit given by Equation 9. Reef width is included in the modeling approach for this study based on results from Hardy et al. (1990) and Smith (1993) and calibration efforts of Militello, Scheffner, and Thompson (2003). The wave approaching the seaward reef face is assumed to decay in height with propagation distance over the reef. The stable decayed wave height reached over a wide reef is given by Equation 9 with tide, storm surge, and ponding included in d_b. When wave height incident to the reef exceeds the stable decayed wave height, the decay with propagation distance over the reef is given by

$$\frac{d(H^2)}{dx} = \frac{-\kappa}{d_b}\left(H^2 - \gamma_b{}^2 d_b{}^2\right) \tag{10}$$

where κ is a decay constant.

Empirical Simulation Technique

Coastal inundation studies, storm damage reduction programs, and design of coastal structures typically require an extreme water level analysis to obtain peak water-surface elevations for planning and design. Because typhoons and hurricanes occur infrequently at a given site, abundant historical water level stages are generally not available and standard ranking methods cannot be effectively applied in stage-frequency analysis. Thus, numerical models are often invoked for simulating a larger population of storm-surge events. Traditionally, modeled tropical storms have been synthesized via a joint probability method (JPM) to describe storm attributes, such as maximum wind speeds and pressure deficits. A set of hypothetical storms is built from a combination of parameter values obtained by statistical analysis of historical storms.

The JPM requires that all parameters are statistically independent. However, storm parameters are not statistically independent, and the assumption of independence leads to errors when the JPM approach is taken. Because storm parameters are related, random grouping of parameters can cause simulation of storms that may not occur in nature. For example, one parameter may be assigned a value typical of a weak storm, whereas a second parameter may be assigned a value representative of an intense storm. Thus, an artificial level of uncertainty is introduced into the stage-frequency computations. For this study and other recent CHL studies, an alternative approach, the EST, has been taken. The EST preserves the interdependence of typhoon parameters, which is an advantage over the JPM. Details of the EST are given in Borgman et al. (1992); Scheffner and Borgman (1993), and Scheffner et al. (1999).

Description of technique

EST is a statistical resampling technique that uses historical data to develop joint probability relationships among the various measured storm parameters. In contrast to the JPM, there are no simplifying assumptions concerning development of the probability density functions describing historical events. Thus, the interdependence of parameters is maintained. In this manner, parameter probabilities are site-specific, do not depend on fixed parametric relationships, and do not assume parameter independence. Thus the EST is distribution-free and nonparametric.

For this study, the EST was developed to generate numerous multi-year intervals of possible future typhoon events for the study site. The ensemble of modeled or simulated events is consistent with statistics and correlations of past storm activity at the site. Furthermore, the EST permits random deviations in storm behavior (when compared to historic events) that could occur in the future. For example, simulated typhoons are permitted to make landfall at locations other than those made by historical storms. These random deviations can also result in more intense storms than the historical events themselves, allowing for the possibility of a future typhoon being the storm of record.

The simulation approach requires specifying a set of parameters that describes the dynamics of some physical system, such as typhoons. These parameters, which must be descriptive of both the physical process being modeled and the effects of that process, are defined as an N-dimensional vector space. The parameters that describe the physical attributes of the process are referred to as input vectors. For example,

$$\underline{v} = \left(v_1, v_2, v_3, \ldots, v_N\right) \tag{11}$$

In the case of typhoons, pertinent input vectors include: the central pressure deficit, the radius to maximum winds, minimum distance from the eye of the storm to the location of interest, forward speed of the eye, and the tidal phase during the event. These values can be defined for each specific location and correspond to each particular historical or hypothetical event of the total set of storm events used in the study.

The second class of vectors involve some selected response resulting from the N-dimensional parameterized storm, i.e.,

$$\underline{r} = \left(r_1, r_2, r_3, \ldots, r_M\right) \tag{12}$$

For typhoons, response vectors can include maximum water level, shoreline erosion, dune recession, wind-generated wave height and period, bottom erosion, overtopping rate, or any response that can be attributed to the passage of the storm. The maximum total water-surface elevation is often the response vector of greatest interest.

Although response vectors are related to input vectors

$$v \Rightarrow r \tag{13}$$

the interrelationship is highly nonlinear and involves correlation relationships that cannot be directly defined, i.e., a nonparametric relationship. For example, in addition to the storm-input parameters, storm surge is a function of local bottom topography, shoreline slope and exposure, ocean currents, etc., as well as their spatial and temporal gradients. It is assumed that these combined properties are implicit in the response vector. Atmospheric, hydrodynamic, and other models are applied as needed to compute water level response vectors as a function of the input vectors and local bottom topography together with shoreline configuration. Other response vectors such as sediment transport, shoreline response, and dune recession require application of additional models.

A representative subset of storms is selected from the full set of historical storms. This subset is referred to as the training set. Those storms comprising the training set are subsequently used as input to numerical models for computing the desired response vectors. The training set usually includes historical events but may include historical storms with a deviation or perturbation, such as a typhoon with a slightly altered path. Some historical events may also be deleted from the training set if two events are nearly identical such that both would produce the same response.

The training set of storms can be augmented with additional storms contained in the historical data set. Storm events augmenting the training set are referred to as the statistical set of storms. Whereas numerical models are used for calculating response vectors for those events in the training set, response vectors for the statistical set of storms are interpolated using the training set response vectors. Thus, stage-frequency relationships can be generated using the entire historical data set without need of simulating all storms in that data set.

With the augmented storm data set (i.e., training and statistical storm sets), the EST produces N simulations of a T-year sequence of events (typhoons), each with their associated input vectors and response vectors. Because there are N-repetitions of a T-year sequence of events, a variational analysis of the results can be performed with respect to median, worst, least, standard deviation, etc. The following describes the procedures by which the input and response information is used to produce multiple simulations of multiple years of events.

Empirical simulation

Two criteria are required of the T-year sequence of events. The first criterion is that individual events must be similar in behavior to historical events in order that the interrelationships among the input and response vectors remain realistic. For example, a typhoon with high central pressure deficit and low maximum winds is not a reasonable event – the two parameters are not independent although their exact dependency is unknown.

Simulation of realistic events is accounted for in the nearest-neighbor interpolation resampling technique developed by Borgman et al. (1992). A storm event is identified by random sampling from the total storm population. The procedure is equivalent to drawing and replacing random samples from the full storm event population.

Because simulated events correspond to a specific location, the second criterion to be satisfied is that the total number of storm events selected in the T-years must be statistically representative of the number of historical events that have occurred at the area of study. For this study, 28 typhoon events were identified that passed within 370 km (200 miles) of Rota and Guam during the 53-year period extending from 1945 through 1997.

Output from the EST program is *N* repetitions of T-years of simulated storm event responses. It is from these responses that frequency-of-occurrence relationships are computed. The computational procedure followed is based on the generation of a probability distribution function corresponding to each of the T-year sequences of simulated data. Additional detail about the EST is given by Scheffner et al. (1999).

4 Implementation of Storm Surge Model

The process required for application of a long-wave hydrodynamic numerical model at a particular site includes grid generation, model calibration, model validation, and production runs. Accuracy of model results is greatly influenced by the accuracy of boundary and forcing conditions, representation of bathymetry over the model domain, and to a lesser degree, the values of certain calibration parameters. Model calibration involves adjustment of the calibration parameters to maximize agreement between model results and measurements.

The water level gauge nearest to Rota is located in Apra Harbor, Guam. Data from this gauge were used for storm surge model calibration and validation in a recent study by Thompson and Scheffner (2002). That calibration and validation is applicable to the present study, as well. The present study grid has the same offshore boundary, tidal forcing, open ocean grid resolution and bathymetry, and islands as the Apra Harbor grid. The principal differences are that the present grid has increased resolution around Rota and coarse resolution around Guam. Tide and storm surge modeling at a small island such as Rota with open coasts and deep surrounding waters is not much changed from open ocean conditions and is not sensitive to details of island bathymetry. Thus, the present grid can be confidently applied to Rota.

Model astronomical tide results for the month of January 1997 illustrate tidal behavior at Rota (Figure 8). Mean tide range is only 15 cm (0.5 ft). The tide is characterized by a relatively large diurnal inequality. High tides are generally slightly greater than msl and lower low tides typically drop well below msl. This tidal behavior is similar to that for Apra Harbor, though the tide range at Apra Harbor is larger. The model indicates that tides on the east side of the village, in the Sasanhaya embayment, are nearly identical to those on the west side.

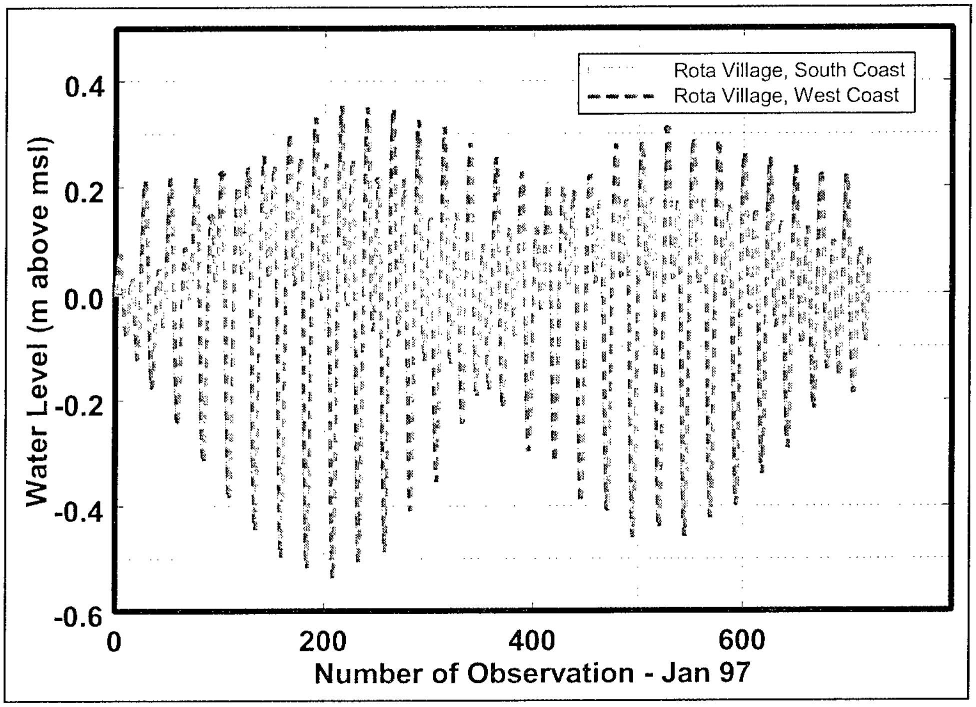

Figure 8. Model astronomical tide, Rota, January 1997

5 Development of Stage-Frequency Relationships

Stage-frequency relationships were developed for the island of Rota in four tasks. First, the training set of storms was developed from a storm database for the western Pacific Ocean, and the PBL model was applied to calculate wind fields associated with each storm in the training set. Second, the storm-surge model was applied with wind and atmospheric pressure forcing from the PBL model as time-dependent input. Time-series of storm-surge elevations associated with each storm were calculated for specified stations. Third, time series of wave parameters were calculated by application of the wave and wave-transformation models. Time series of ponding level, setup, and runup were calculated for each profile location in the study site. Fourth, the EST was applied to compute stage-frequency relationships based on the typhoon event parameters and calculated storm water level elevations.

This chapter briefly reviews procedures implemented for developing stage-frequency relationships for the study area and presents study results. Previous chapters give more detailed background on some aspects of the study. The set of historical storms included in the training set is given in and discussed in Chapter 2 (Table 1). Storm tracks are provided in Appendix A. Detailed discussion of the modeling approach is given in Chapter 3.

Storm Surge/Tidal Elevation Relationship

Storm-surge elevations are dependent on water depth as well as intensity and angle of approach of the storm. The most accurate method for calculation of surge is inclusion of tides in the storm-surge simulation. However, this approach is not practical for stage-frequency analysis because numerous tidal phases would have to be modeled for each storm in the training set to acquire a representative set of surge and tide combinations. An alternative approach was taken in this study, as in previous studies, to estimate the combined water-surface elevation of the surge and tide. Simulations were performed for each of the 32 storms in the training set, where the still-water level was taken to be msl. Tides were not included in the computations. Because storm surges are small for the study site, the water-surface elevation for the combined surge and tide can be approximated as a linear superposition of the two. Thus, still-water level for stage-frequency computations was calculated by addition of the surge to a specific tidal elevation.

A total of 45 numerical gauge stations was specified as locations for surge output from the storm-surge model. The key nearshore stations are shown in Figure 9. Stations not shown were secondary sites located seaward of the reef to assess reef effects on storm surge (which were minimal). Appendix B gives the latitude and longitude of all stations. Water-level values were stored at 15-min intervals at each station.

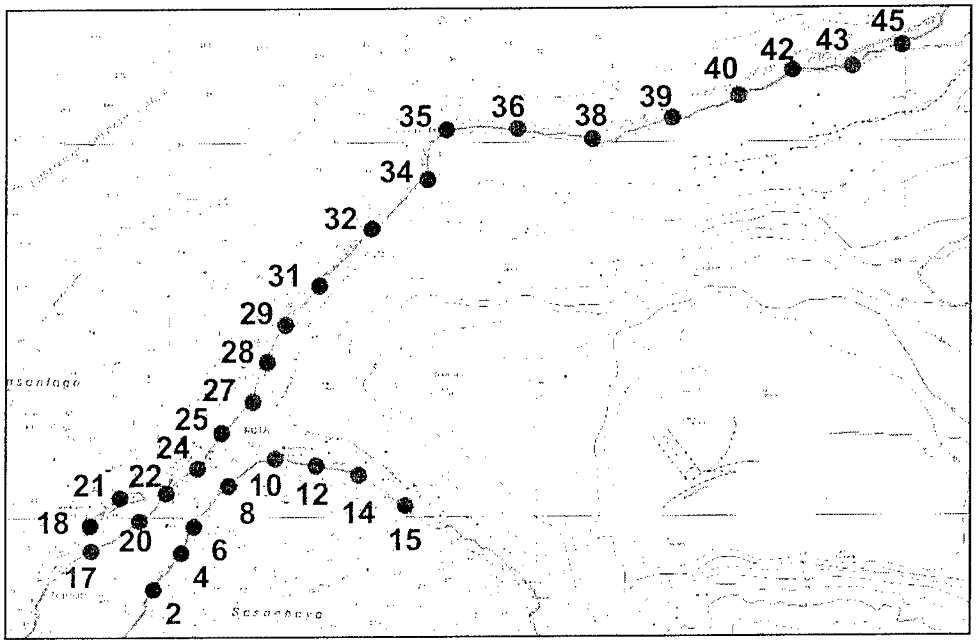

Figure 9. Key nearshore storm surge station locations for Rota

Spectral Wave Transformation

Waves in the open ocean calculated by the WISWAVE model were transformed to near-breaking by application of WAVTRAN, described in Chapter 3. Waves in the offshore and transformed time series were at 1-hr intervals throughout each storm. Estimates were made of the general nearshore depth contour and shoreline orientation closest to each of the numerical gauge locations specified in Appendix B. In addition, estimates of sheltering angle bands were made based on shoreline geometry. For numerical gauge locations 2-16, located in the Sasanhaya embayment, substantial one- or two-sided sheltering was applied. For numerical gauge locations 17-45, along the exposed northwest- and north-facing coasts, little or no sheltering was applied.

Initially, waves were transformed to a water depth of 10 m (33 ft). If maximum significant wave height during the typhoon exceeded 4 m (13 ft) (0.4 times the water depth), WAVTRAN was rerun to transform to a deeper nearshore depth. Nearshore depth was increased in 5-m (16-ft) increments until maximum significant wave height during the storm was less than 0.4 times the depth or until the nearshore depth reached 30 m (98 ft). This transformation approach is expected to produce realistic incident significant wave heights for calculation of nearshore processes.

Wave Level Over Reef

Time series of storm surge and near-breaking waves seaward of the reef were combined to calculate processes over the reef and at shore. Wave ponding over nearshore fringing reefs was calculated at 15-min intervals throughout each storm, as discussed in Chapter 3.

Based on calibration tests and the objective of estimating a maximum inundation level, discussed in the following section, average height of the 1 percent highest waves, H_1, was used in place of significant height, H_s, for pre-breaking waves incident to the reef face. Thus, ponding, setup, and runup calculations are all based on H_1 as the incident wave height. The widely-accepted Rayleigh distribution for wave heights in a sea state gives $H_1 = 1.67 * H_s$. Elevation of the reef crest was taken as 0.6 m (2 ft) below msl. Depth over the reef crest was calculated based on a water level that includes astronomical tide and storm surge, and the guidance of Seelig (1983) was applied. When depth over the reef was less than 2 m (6.6 ft), which was typically the case, ponding was calculated for both cases in Table 6 and an interpolated ponding value was used.

Astronomical tide was included as a single level (msl) in this study for three reasons. First, the tide range is relatively small. Second, tide levels at this location are characteristically in a very narrow range between msl and mhw most of the time, as discussed in Chapter 4. Finally, tidal variations for this application can be effectively introduced in EST modeling, as discussed later.

Wave Setup and Runup

To calculate wave ponding, setup, and runup and estimate coastal inundation levels, a series of transects was established along the inhabited coasts of Rota. A total of 87 transects fell within the study area. Transect profiles and topographic elevation contours were provided by the Honolulu District. The topographic contours were compiled by photogrammetric methods from aerial photography taken in February 1999 and June 1996. Elevations were specified relative to msl. In addition to the measured profile data, reef width normal to the beach was estimated from the topographic maps. Profiles were extended seaward by the estimated reef width. Each profile is paired with a nearby storm surge station (or two stations bracketing the profile if storm surge is better interpolated between adjacent stations). Transect profile numbers and corresponding storm surge station numbers from Appendix B are given in Appendix C.

This approach for estimating coastal inundation levels has been used in previous studies at other locations. Although the approach is useful for practical studies, it has some significant limitations. Nearshore wave processes, particularly wave runup at the shore, can be strongly affected by the three-dimensionality of land forms. The modeling approach does not capture this nearshore three-dimensionality. Extreme coastal inundation events along Rota coasts are primarily due to huge waves attacking the shore. Storm surge is only a small component of extreme events. In contrast, storm surge is the major component of coastal inundation along U.S. Atlantic and Gulf of Mexico coasts. Thus, in an exposed island environment such as Rota, accuracy of coastal inundation calculations is much more dependent on accurate modeling of waves, which naturally vary greatly over short distances, much more so than storm surge. More comprehensive modeling tools are under development but were not available at the time of this study.

The traditional modeling approach, described in Chapter 3, is aimed at estimating a significant inundation level at shore. The actual water level at shore varies constantly as waves run up and down the shore face, ponding level over the reef pulses up and down, and incident wave characteristics fluctuate. The significant inundation level at shore is representative of the higher water levels produced by these time-varying processes over a time period when the underlying sea state and storm conditions are relatively stationary, typically 1 hour.

An objective of this study, as in a companion study of American Samoa (Millitello, Scheffner, and Thompson 2003), is to estimate maximum inundation level at shore. This level is higher than the significant inundation level. Maximum inundation level was estimated by adapting the nearshore modeling approach in Chapter 3 to produce more extreme water levels and calibrating/ verifying with observed maximum inundation levels. The primary observations were collected by FEMA after Hurricane Ofa impacted American Samoa in February 1990. Details are given by Militello, Scheffner, and Thompson (2003).

Changes to the Chapter 3 approach to produce estimates of extreme water level, resulting from the American Samoa calibrations, include increasing significant wave height incident to the reef to represent H_I and using a value of $\gamma_b = 0.78$ in Equation 9. Although the American Samoa calibrations resulted in $\kappa = 0.02$ in Equation 10, subsequent calibration at Inarajan, Guam, suggested $\kappa = 0.03$. Since Guam and Rota are near neighbors, the Guam calibration was used for κ in this study. During an intense nearby typhoon, water depth over the reef (including tide, storm surge, and ponding) can exceed 2.4 m (8 ft), giving nearshore wave heights shoreward of a wide reef of over 1.9 m (6 ft). Nearshore wave height can be considerably higher when the fringing reef is narrow.

Profiles 18-20 required an additional consideration. These profiles are partially sheltered by Anjota Island, which parallels the shore and reaches elevations of 3.7-5.2 m (12-17 ft) msl over much of its length. The island is connected to Rota by a shore-perpendicular roadway with crown elevation of 3.4 m (11 ft) msl. Since Anjota Island lies within the fringing reef, approximately 150 m (500 ft) from shore and 90 m (300 ft) from the seaward edge of the reef, waves were assumed to be completely refracted and traveling straight toward shore when they reached the island. Guidance for diffraction of directionally-spread, spectral waves around a semi-infinite breakwater was applied to estimate the effect of sheltering by Anjota Island (Headquarters, U.S. Army Corps of Engineers, 2002). Diffraction coefficients were determined based on a local water level of +2.4 m (+7.8 ft) msl and 16-sec peak wave period, representative of the most severe storms modeled. The coefficients can be expected to be conservative for less severe storms, which typically have lower water levels over the reef and shorter wave periods. Estimated diffraction coefficients (significant wave height at sheltered location divided by significant wave height incident to Anjota Island) for Profiles 18-20 are 0.8, 0.4, and 0.71, respectively.

Wave setup and runup time series were estimated at the 87 coastal profiles for the 32 storms using the approach described in Chapter 3 and in the previous paragraphs. Runup level, calculated with the composite slope method, was multiplied by a runup reduction factor of 0.9 to account for effects of slope roughness and porosity. The runup reduction factor value was chosen based on guidance in the *Shore Protection Manual* and past experience. Runup level includes wave setup. Separate estimates of wave setup, apart from runup, are needed because maximum still-water levels are also a study objective; and wave setup is considered to be a constant increase in local water level (for given tide, surge, and incident wave conditions).

The highest runup levels computed for five profiles in the Sasanhaya embayment exceeded the maximum profile elevation. These profiles, facing southeast along the narrowest part of the Taipingot peninsula, received special consideration because they can be overtopped during severe storms. At the request of the Honolulu District, the portion of these profiles above +3.66 m (+12 ft) msl was treated as a uniform slope extending to an elevation beyond possible runup levels. The profiles are 5 through 9 and corresponding slopes (provided by Honolulu District) are 200, 800, 400, 267, and 19 percent, respectively. Stage-frequency information on these artificial slopes includes fictitious runups which will be subsequently reduced with a low bluff methodology applied by Honolulu District prior to flood mapping.

Validation of Maximum Water Levels

The methodology used to estimate maximum water level along Rota coasts has been calibrated to observations at other locations. Until the final phase of this study, no observations were available to validate the methodology on Rota. However, late in the study, the Honolulu District was able to collect observations from a moderate storm. The eye of Typhoon Chataan passed just south of Guam on July 5, 2002, moving toward the northwest. Maximum sustained winds during its approach and passage were 39-41 m/s (75-80 knots). Maximum water level observations were surveyed at 14 points along the Rota coast in the aftermath of Typhoon Chataan. Points are located in the village area at the north end of the Sasanhaya embayment. Study profiles in this area are numbers 10 and 11. The modeled storm that most resembles Typhoon Chataan is Typhoon Nina (0853). Nina had maximum sustained winds, track direction, and forward speed comparable to Chataan. The biggest difference between the two storms is that Nina's track was displaced further north about 1 deg 110 km (70 miles). Since both storms passed well south of Rota and both could generate waves from the strong side of the storm headed into the Sasanhaya embayment, the displacement difference may not be a major impact.

Model maximum water levels from Nina (0853) at profiles 10 and 11 are compared to observations from Chataan nearest the profiles (Table 7). The excellent agreement helps to validate the modeling approach for estimating maximum water levels along the Rota coasts.

Table 7 Comparison of Observed and Modeled Maximum Water Level		
Profile Number	Observation (Chataan), m (ft)	Model (Nina), m (ft)
10	+4.8 (+15.8)	+4.9 (+16.1)
11	+6.8 (+22.3)	+6.5 (+21.2)
Note: Maximum water levels referenced to msl.		

Stage-Frequency Relationships

Stage-frequency relationships were calculated for 87 profiles along the study area by application of the EST. These relationships were computed for maximum water level at intervals of 2, 5, 10, 25, 50, 75, 100, and 500 years. Water levels at intervals up to 100 years are meaningful relative to the historical storm record length (53 years). However, reliable 500-year water levels would require a much longer historical database.

Input for the EST included maximum water level calculated for each of the 32 storms in the training set. The EST was applied to two maximum water level calculations. In one, maximum water level was the total of storm surge, ponding level, and runup (which includes wave setup). The other calculation was based on maximum still-water level, the total of storm surge, ponding, and wave setup. Both provide useful information about coastal inundation levels: maximum water level is the highest level reached by ocean water, reached briefly by the highest runup; maximum still-water level is the highest sustained water level (an average water level over many runup/rundown cycles). Maximum water level at Profiles 5-9 is a fictitious level which will be subsequently reduced by the Honolulu District prior to flood mapping, as discussed previously. Tables of stage-frequency relationship values for each profile are given in Appendix D. Maximum expected water level values and standard deviations are given in the tables. Plots of 100-year water levels and profile topography are given in Appendix E.

In addition to the stage-frequency relationships, values of wave parameters and water level components for each storm at selected profiles are presented in Appendix F. The values correspond to the time during the storm passage at which total water level, including runup, reached its maximum at the profile. These tables provide a perspective on the stage-frequency relationships in Appendix D. For example, the strong impact of one hypothetical variation of Olive (5163) on profiles in the Sasanhaya embayment (profiles 1-14) is evident.

6 Summary and Conclusions

A set of typhoon-induced stage-frequency relationships was developed for inhabited coasts of the island of Rota, Commonwealth of the Northern Mariana Islands. The objective was to assist the Honolulu District in estimating extreme maximum inundation levels and maximum still-water levels with return period of up to 500 years. Calculation of surge, wind and pressure field, and wave characteristics were performed for 28 historical storms and four hypothetical variations of historical storms through application of numerical models. Wave-induced ponding, setup, and runup were calculated at 87 profile locations specified by the Honolulu District.

The PBL model was applied for simulation of storms whose path brought the storm center within a 370-km (200-mile) radius of Rota and Guam. Historical data from the storms were input into the PBL model for calculation of wind and pressure fields. Atmospheric fields calculated by the PBL model were applied as forcing for the long-wave hydrodynamics and wave models.

The long-wave hydrodynamic model ADCIRC was applied for calculation of storm surge in the study area. Model calculations in a previous study on a similar grid with the same exterior boundary and tidal forcing but detailed resolution around Apra Harbor, Guam, the nearest tide gauge location, compared well to National Ocean Service (NOS) tide and storm surge data. For storm surge calculation, ADCIRC used wind and pressure fields calculated by the PBL model as the atmospheric forcing.

Deepwater wave heights, periods, and directions for each storm were calculated by application of the wave model WISWAVE. These deepwater waves were transformed to the seaward slope of the fringing coastal reef by application of the wave-transformation model WAVTRAN.

Storm surge (wind- and atmospheric pressure-induced) was simulated for 32 historical and hypothetical storms and referenced to mean sea level. Because the island of Rota is a volcanic cone with steep sides, shallow shelf areas do not exist around the island. In contrast to the Atlantic Ocean and Gulf of Mexico coasts of the United States, the storm surge does not build appreciably near shore. Consequently, storm surge (without consideration of waves) is generally small and contributes only a small amount to coastal inundation during severe storms. Wave effects, including ponding on the reefs, setup, and runup, are the major causes of high inundation levels during storm events.

The EST was applied to calculate stage-frequency relationships based on historical storm parameters and calculated response to the storms. These relationships were calculated from the maximum total water levels computed for each storm (including storm surge, ponding, and runup) and from the maximum still-water levels for each storm (including storm surge, ponding, and wave setup). Stage-frequency values and their standard deviations were calculated for 2, 5, 10, 25, 50, 75, 100, and 500-year return periods at the 87 profiles. Water levels at intervals up to 100 years are meaningful relative to the historical storm record length (53 years). However, reliable 500-year water levels would require a much longer historical database. The methodology was calibrated to observations so that stage-frequency values for maximum total water level are expected to represent maximum debris line inundation levels.

The present methodology, in which wave setup and runup at shore are calculated along shore-perpendicular profiles without consideration of actual variations in bathymetry and topography on either side of the profiles, is limited in its ability to accurately model coastal inundation levels on the island of Rota. However, the methodology provides useful information about coastal inundation levels. When modeling tools better suited to nearshore processes along island coasts with fringing reefs become available, the possibility of updating this study should be considered.

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Appendix A Typhoon Tracks

This appendix shows typhoon tracks for each storm contained in the Empirical Simulation Technique (EST) training set. Each figure consists of an upper and lower panel. The upper panel shows storm tracks through the immediate vicinity of the islands of interest for the study. Some figures do not show a storm track in the upper panel because the storm did not pass within the bounds of the graphical limits. The lower panel shows storm tracks for the region covered by the numerical grid developed for the study. The outer boundary of the numerical grid is shown as the large circle. Storm tracks can also be seen outside of the grid region. Dots in the upper and lower panels show the 6-hr best track locations for the storms. Arrows indicate direction of storm travel.

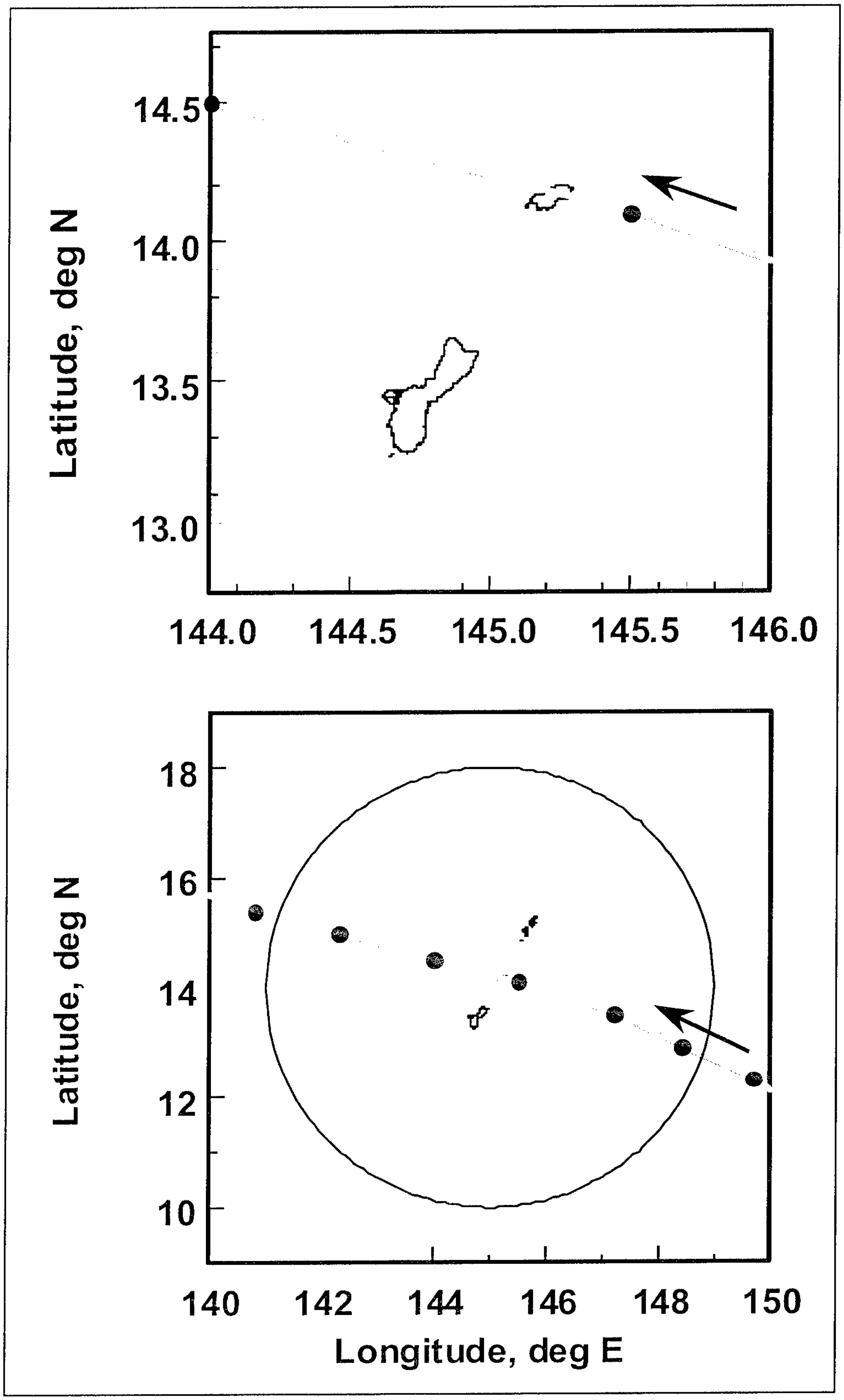


Figure A1. Storm track for Agnes (2348)

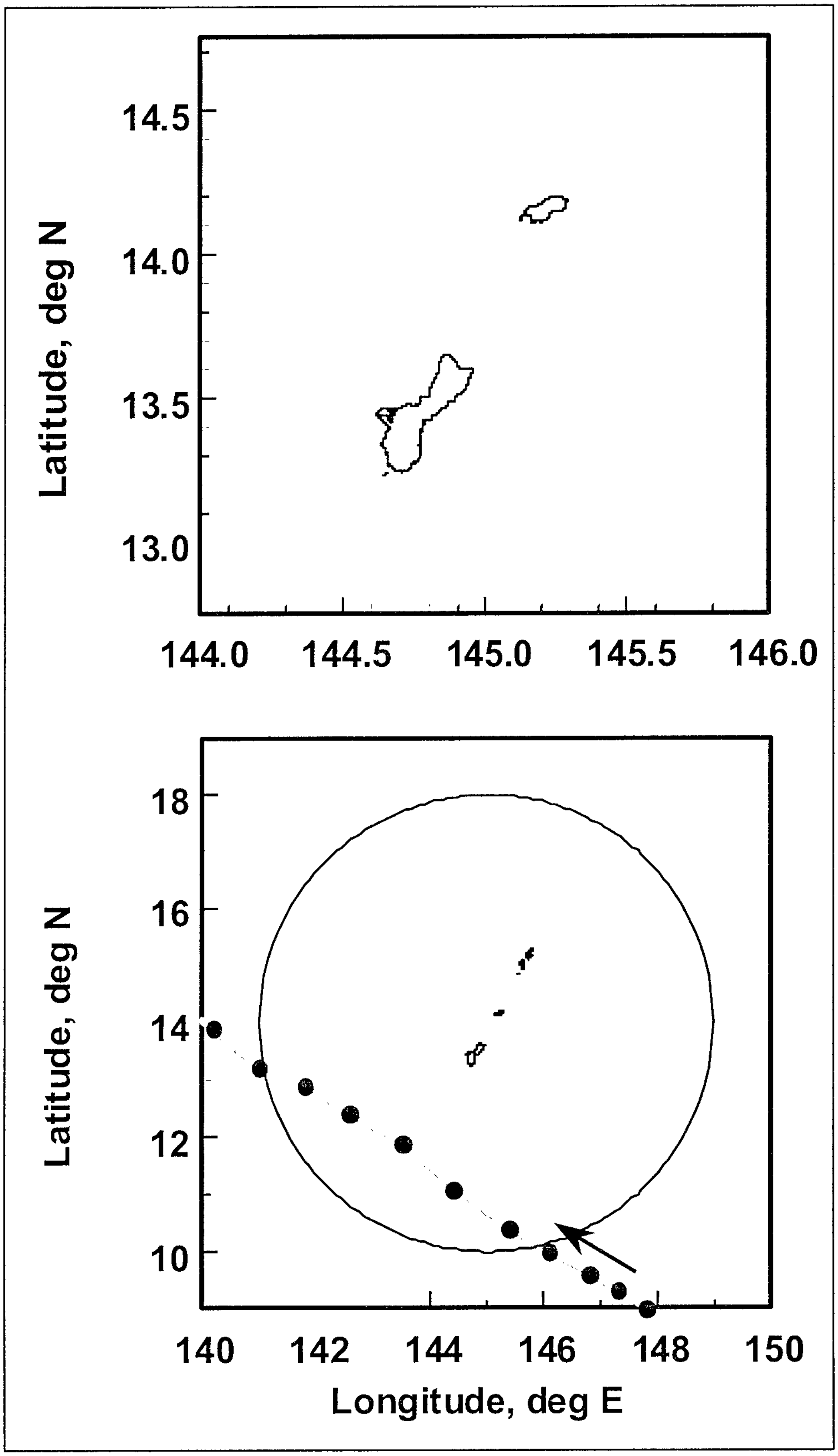


Figure A2. Storm track for Doris (0150)

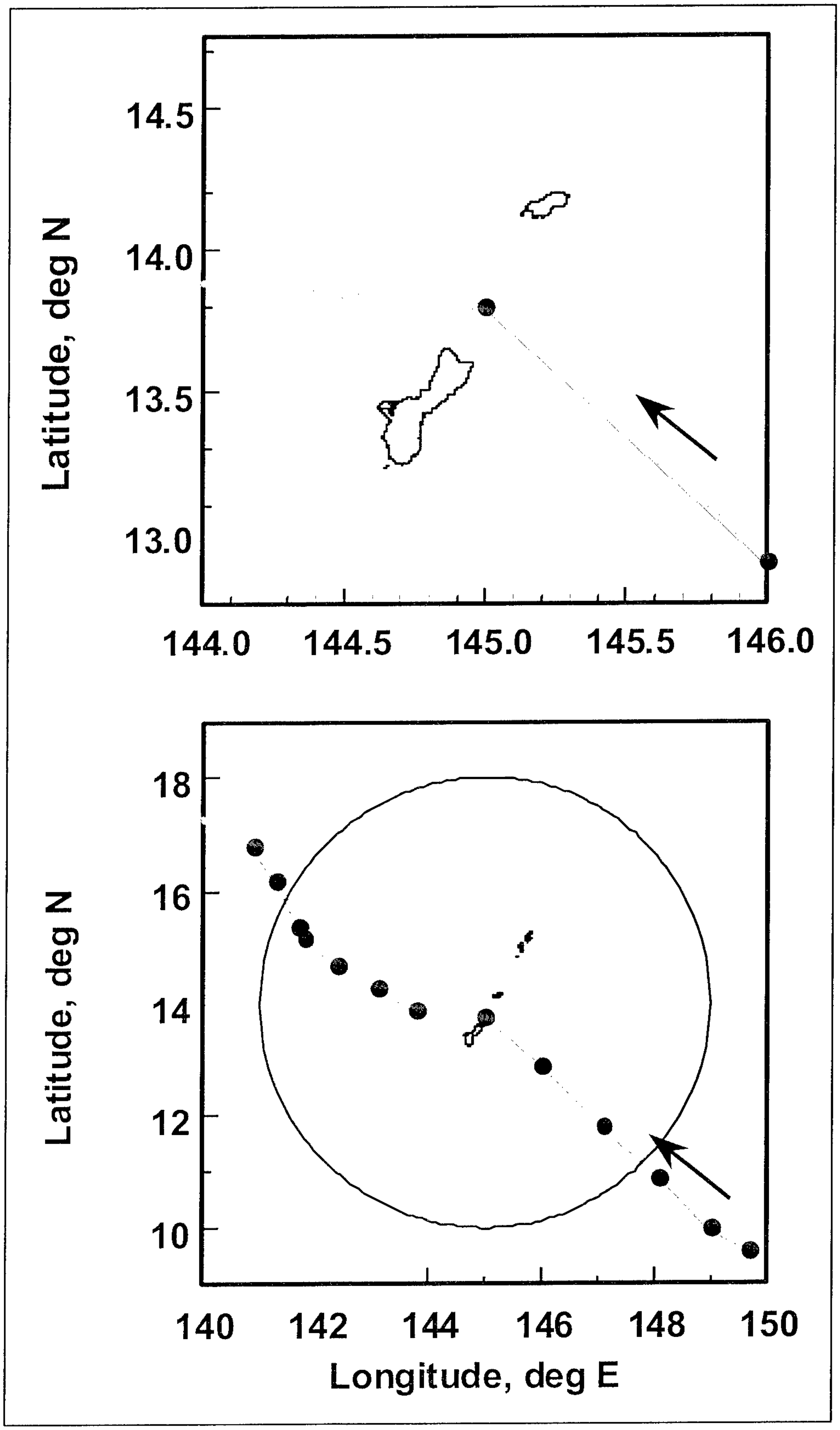


Figure A3. Storm track for Nina (0853)

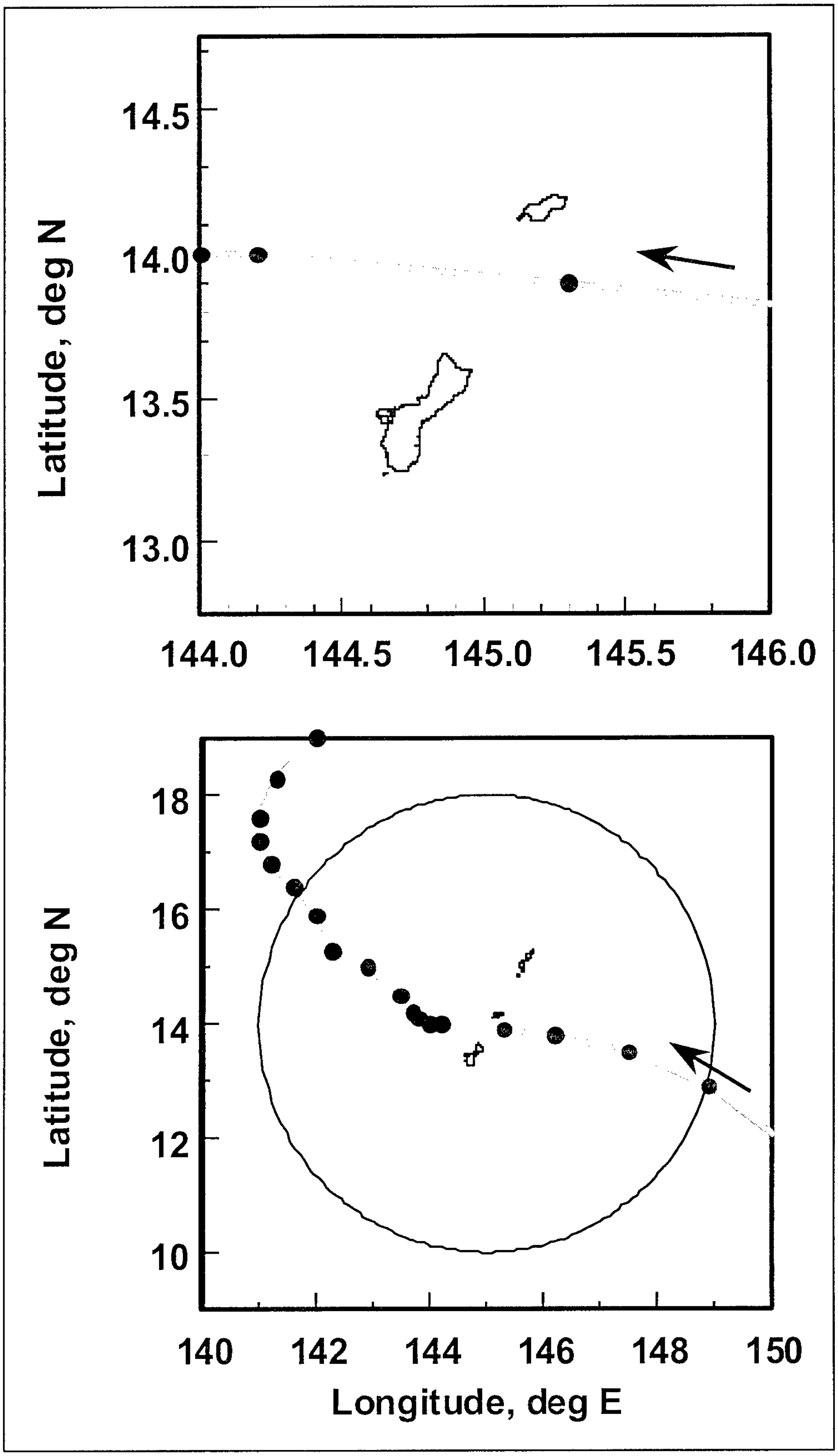


Figure A4. Storm track for Alice (1953)

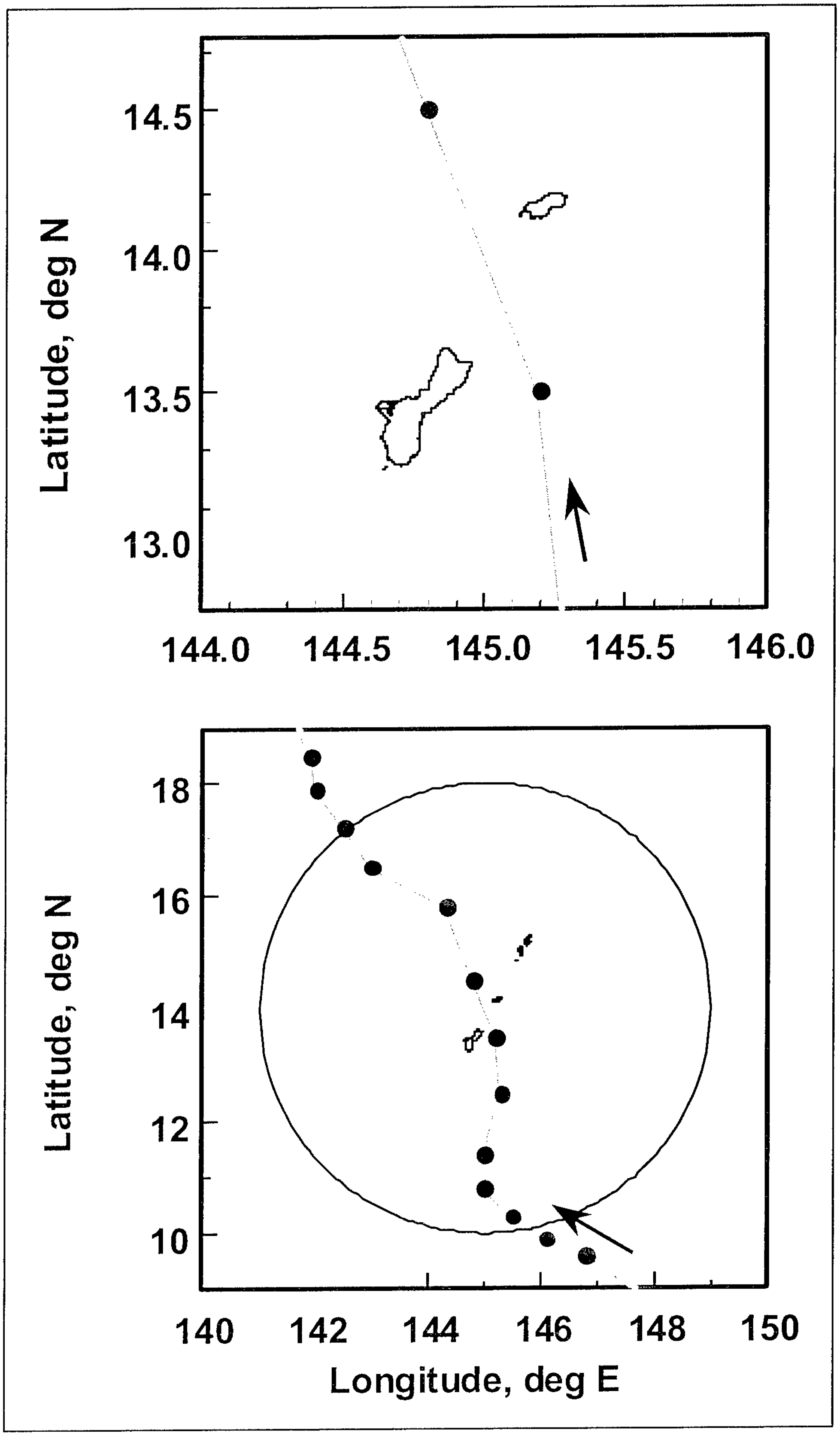


Figure A5. Storm track for Hester (1557)

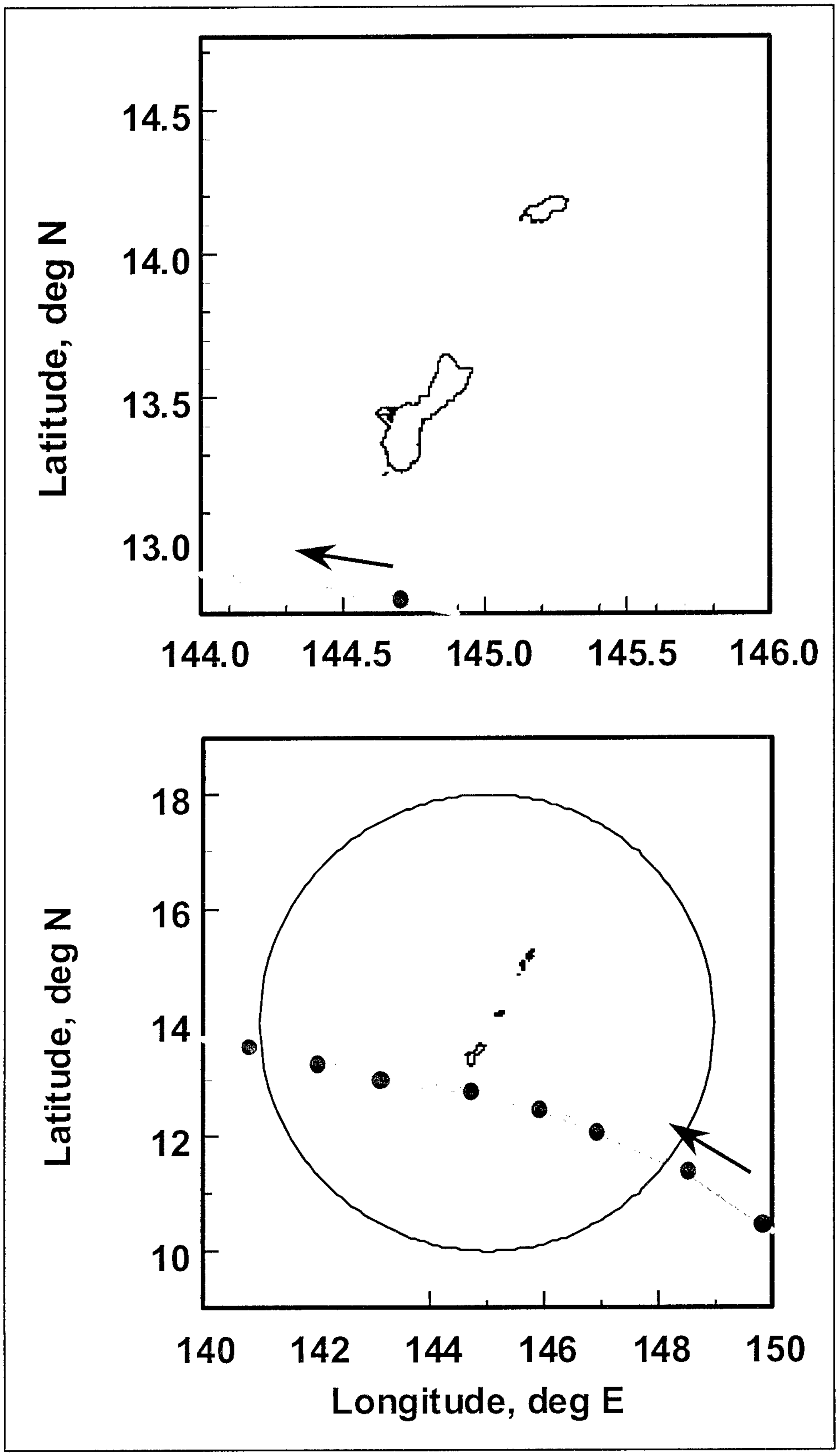


Figure A6. Storm track for Lola (2057)

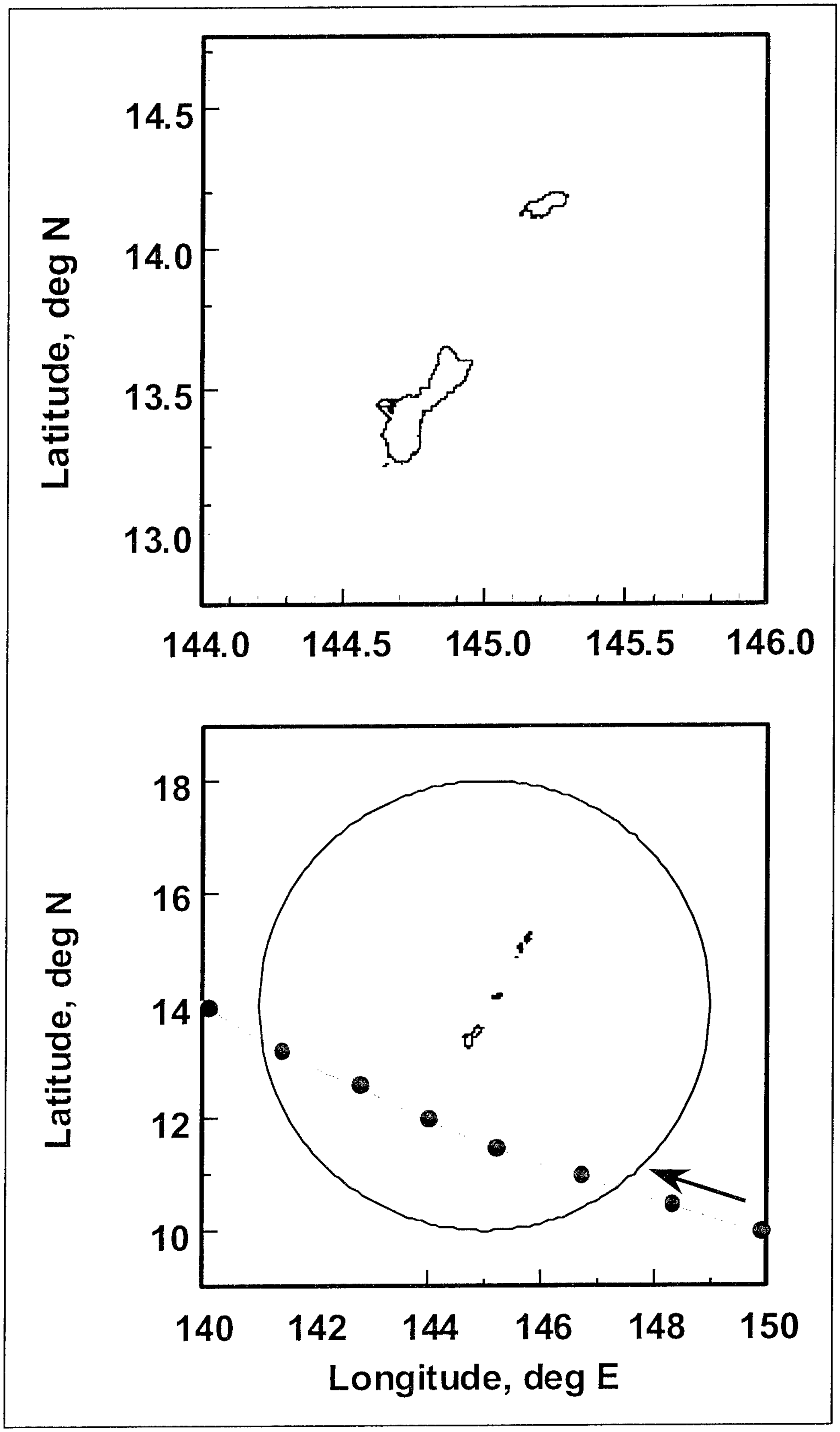


Figure A7. Storm track for Nancy (1861)

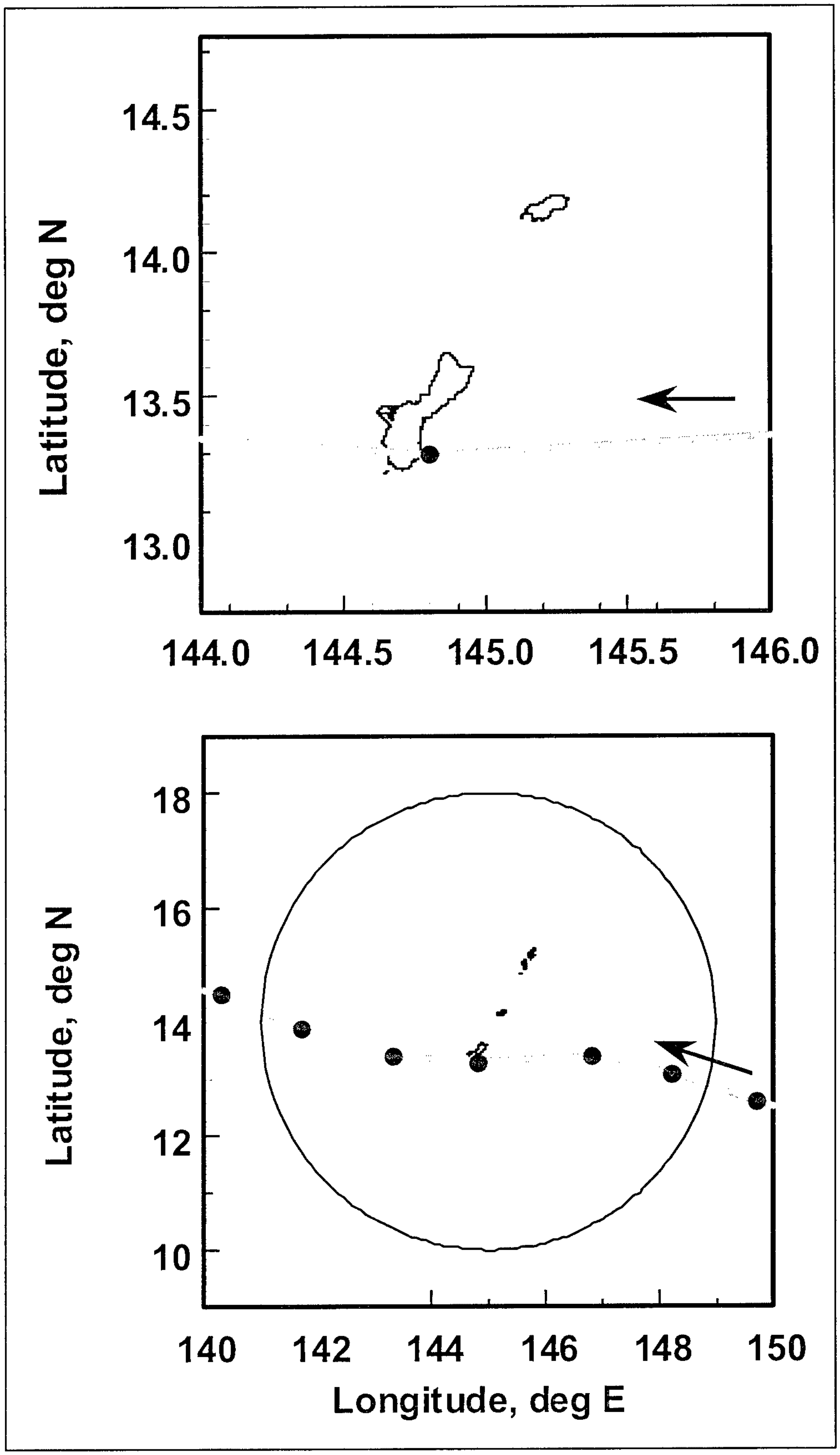


Figure A8. Storm track for Karen (2762)

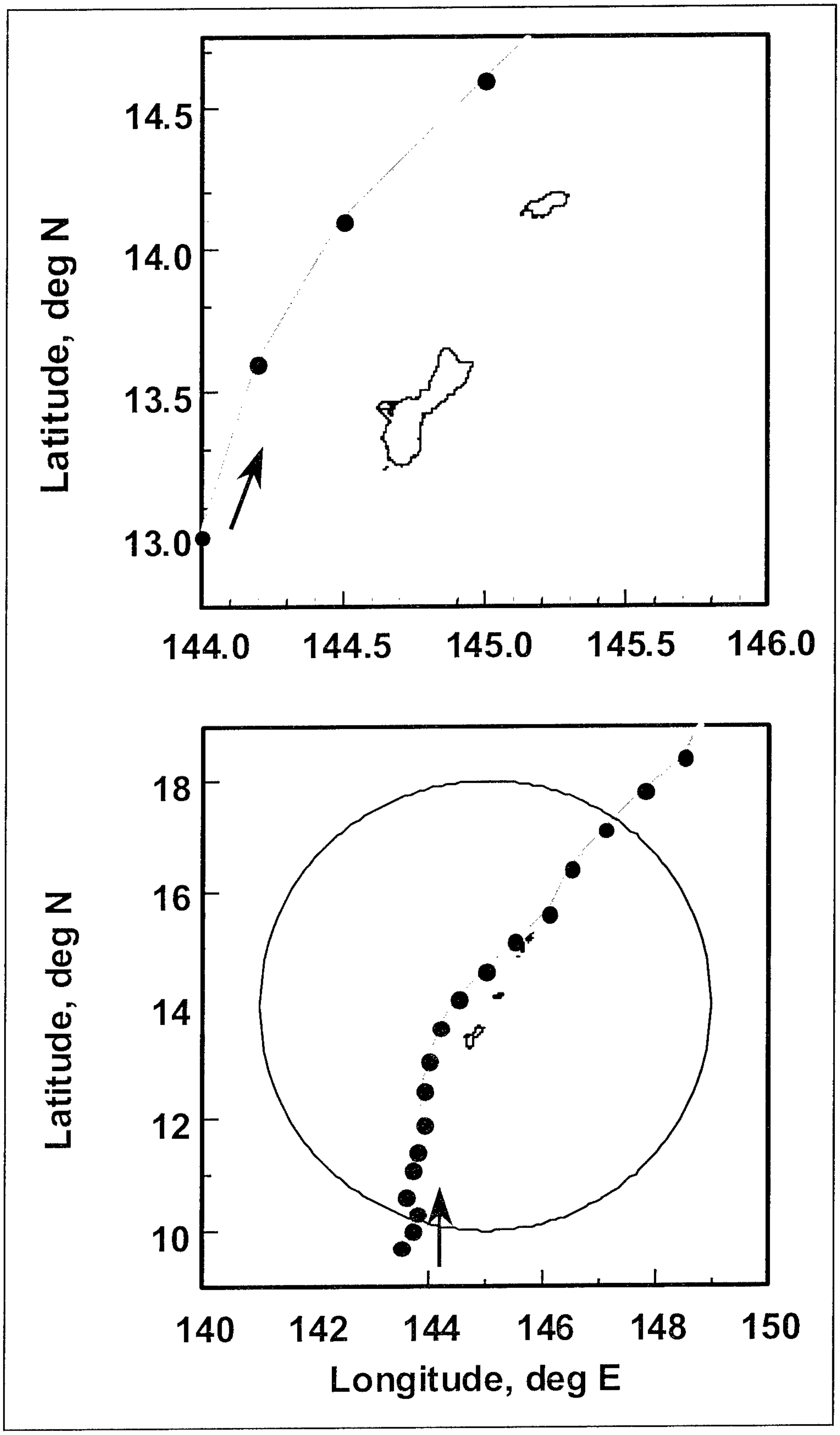


Figure A9. Storm track for Olive (0163)

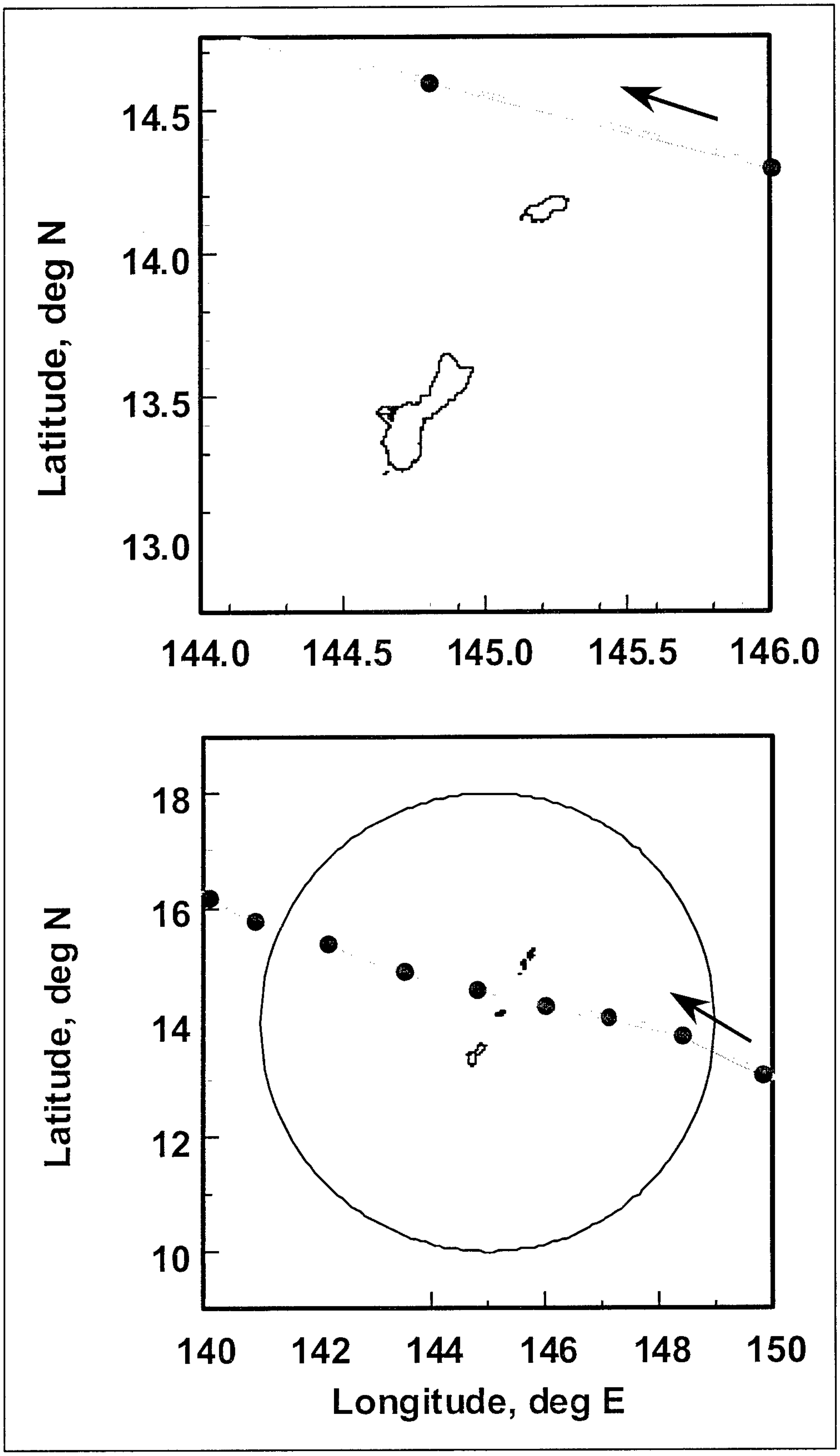


Figure A10. Storm track for Susan (2563)

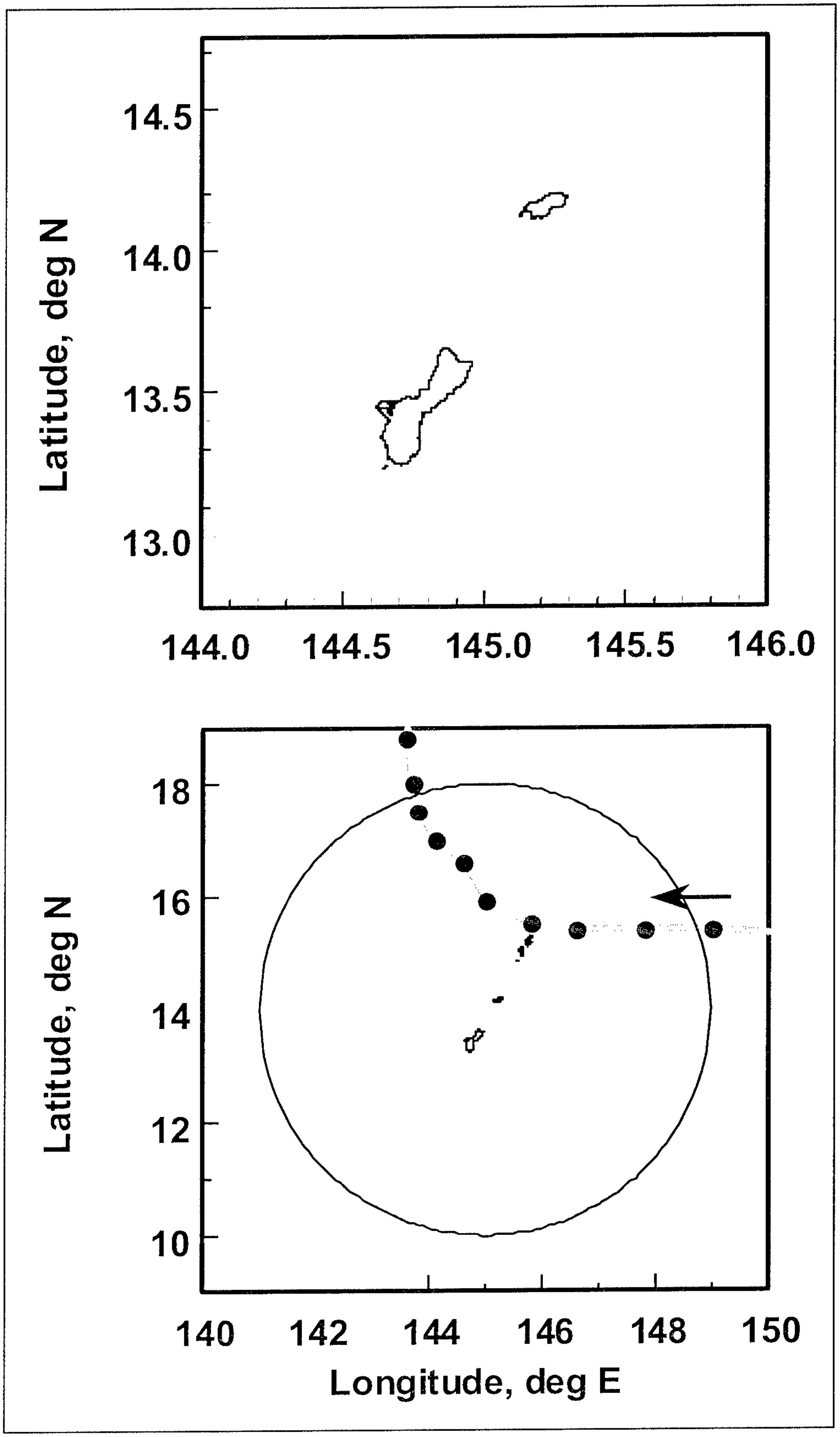


Figure A11. Storm track for Bess (2965)

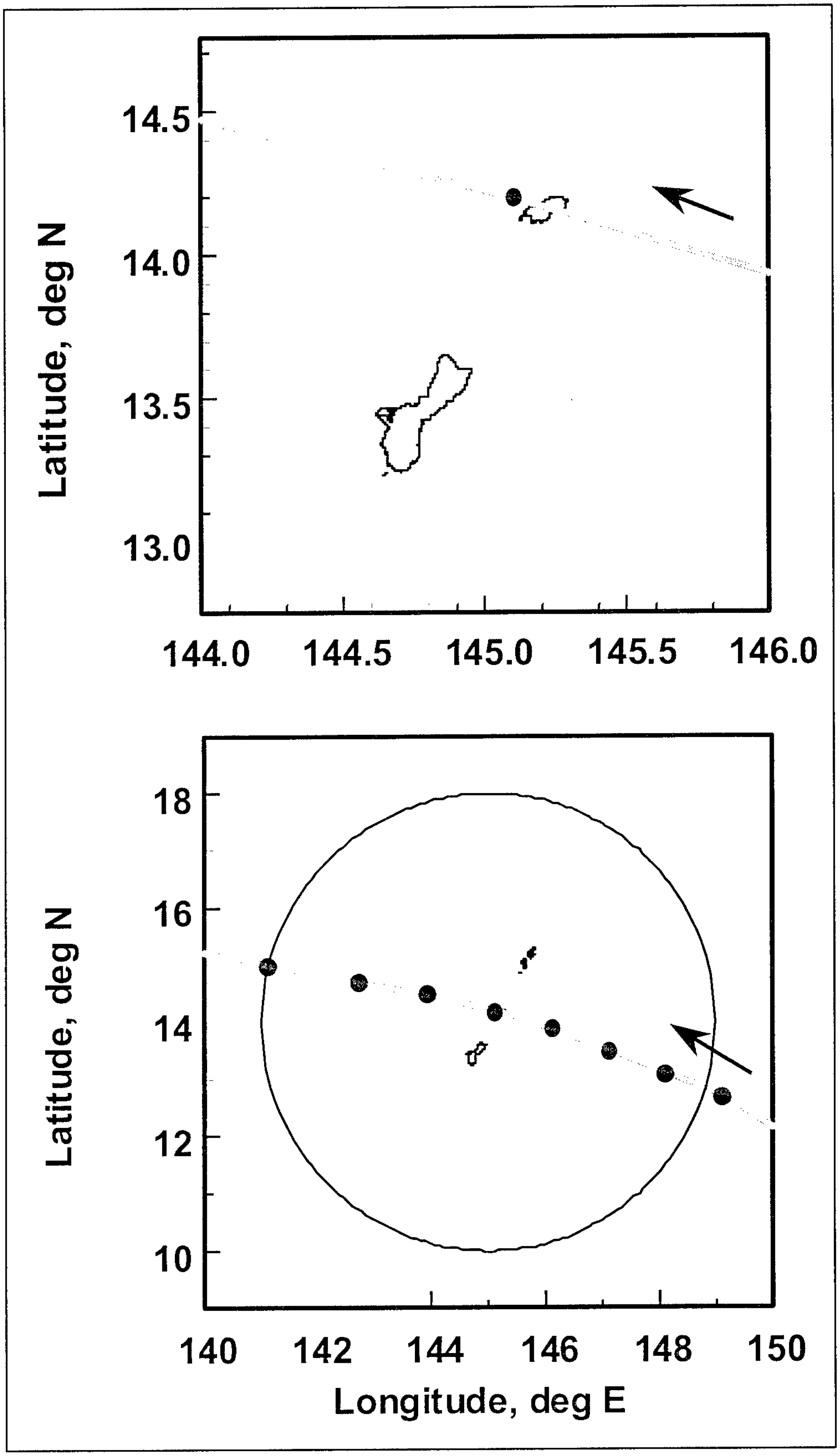


Figure A12. Storm track for Gilda (3367)

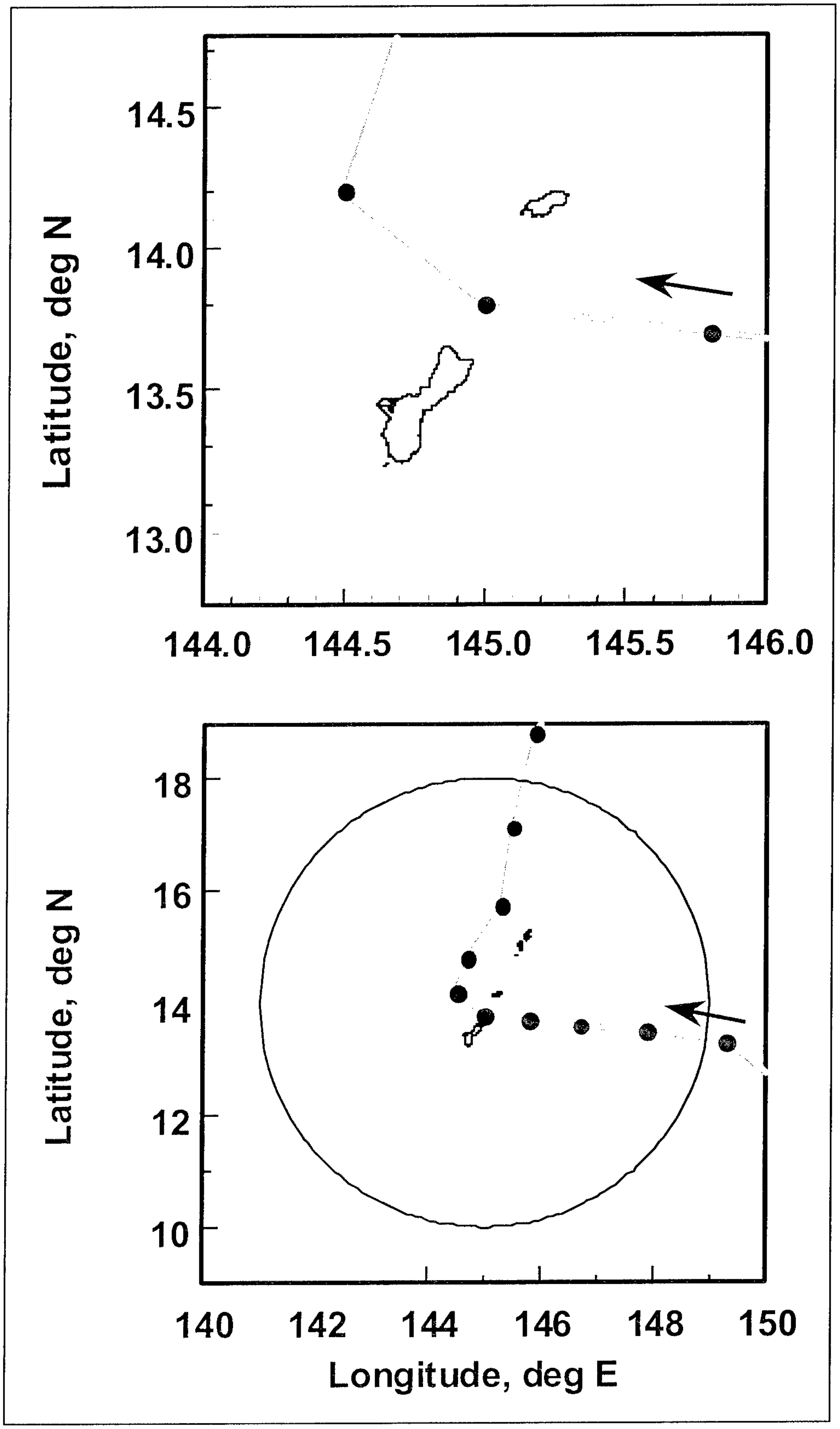


Figure A13. Storm track for Irma (2168)

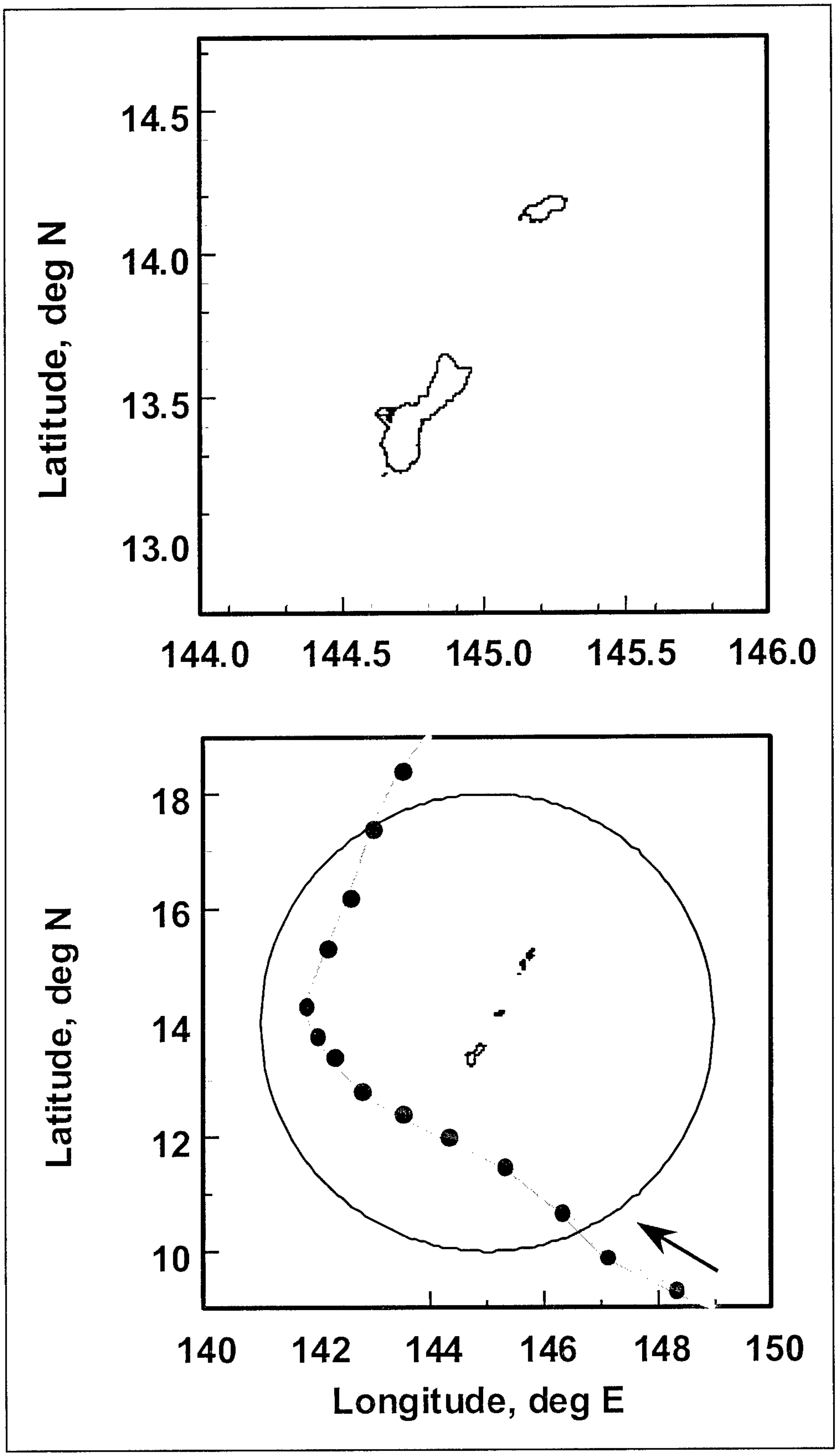


Figure A14. Storm track for Amy (0571)

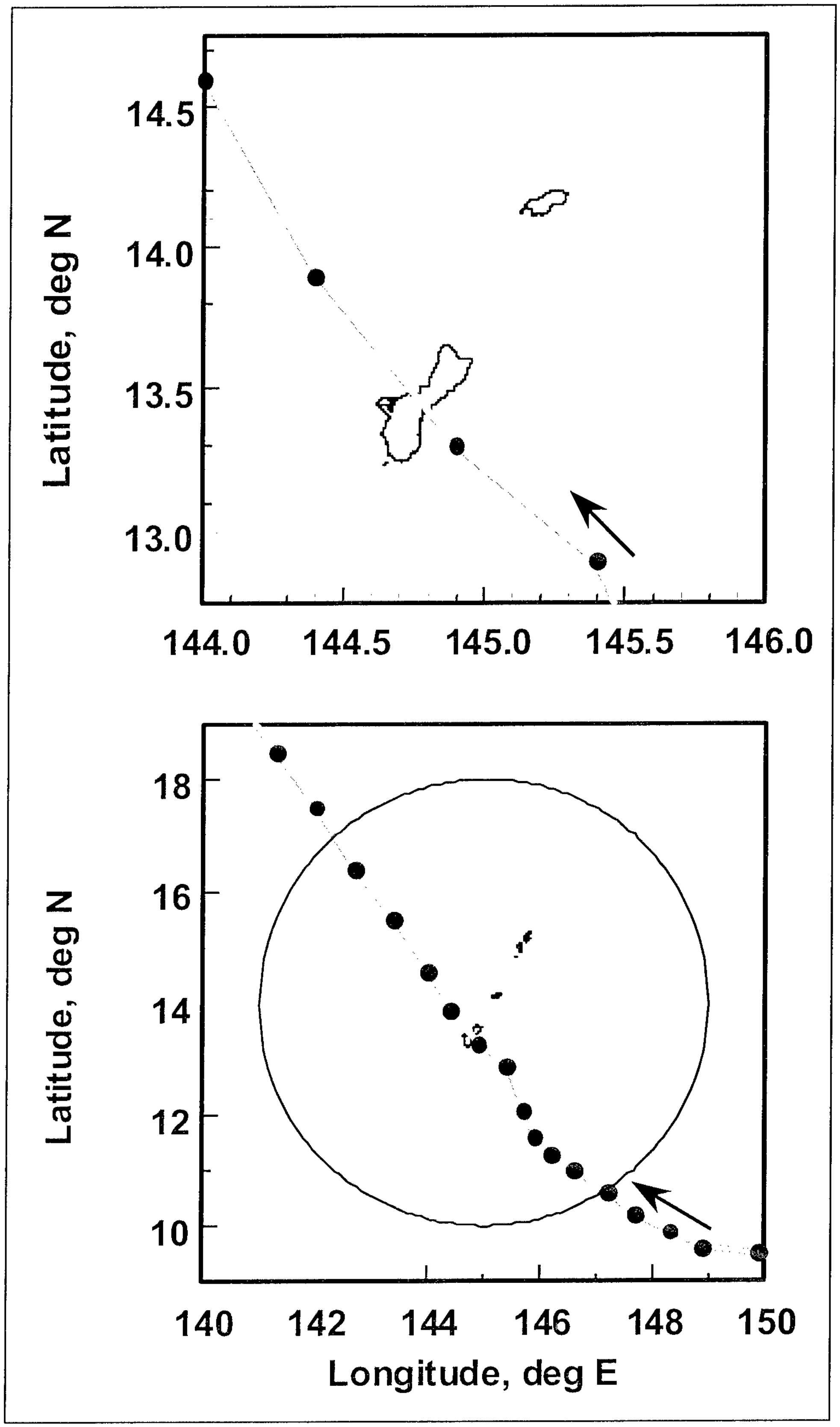


Figure A15. Storm track for Pamela (0676)

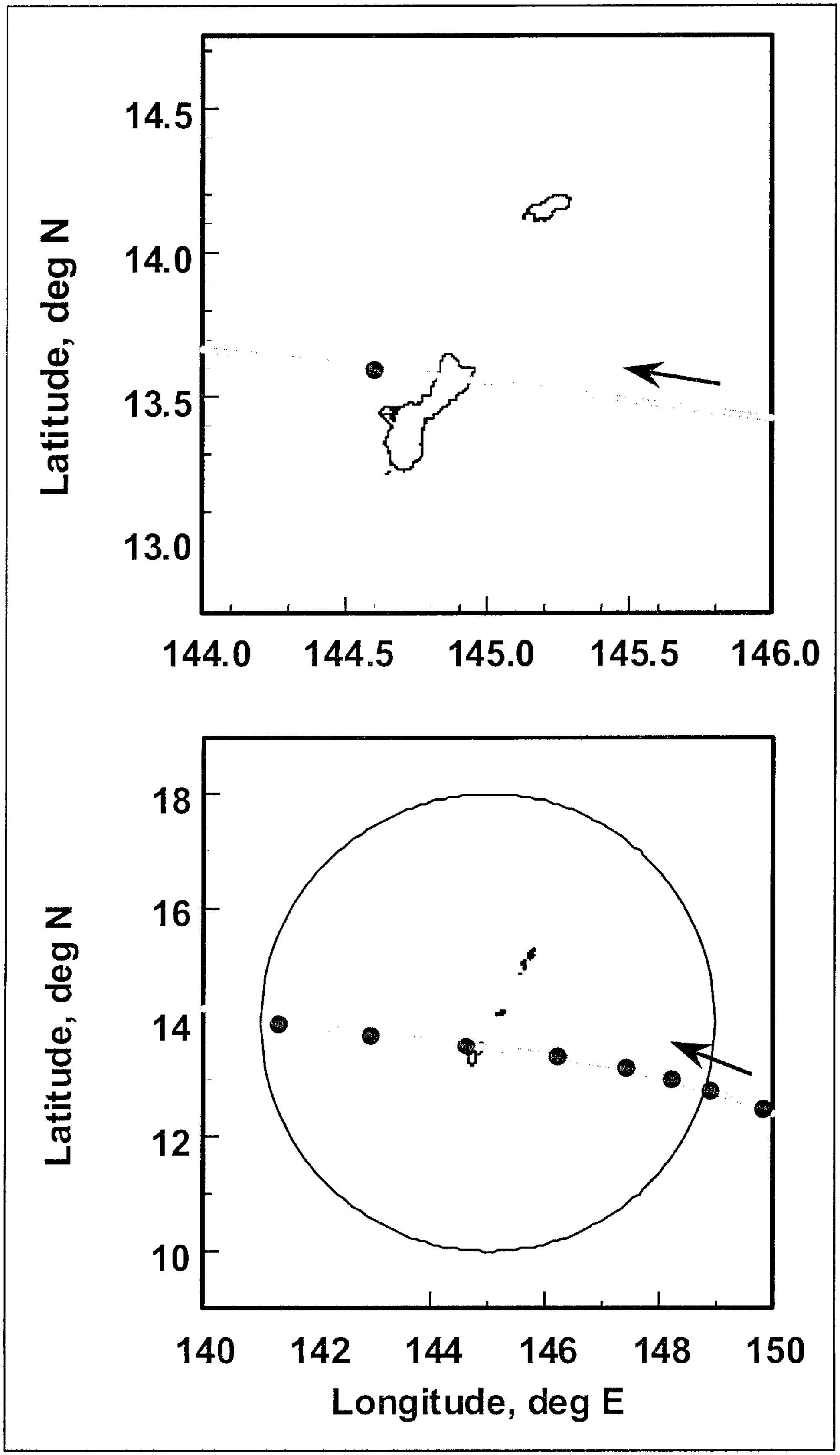


Figure A16. Storm track for Kim (1977)

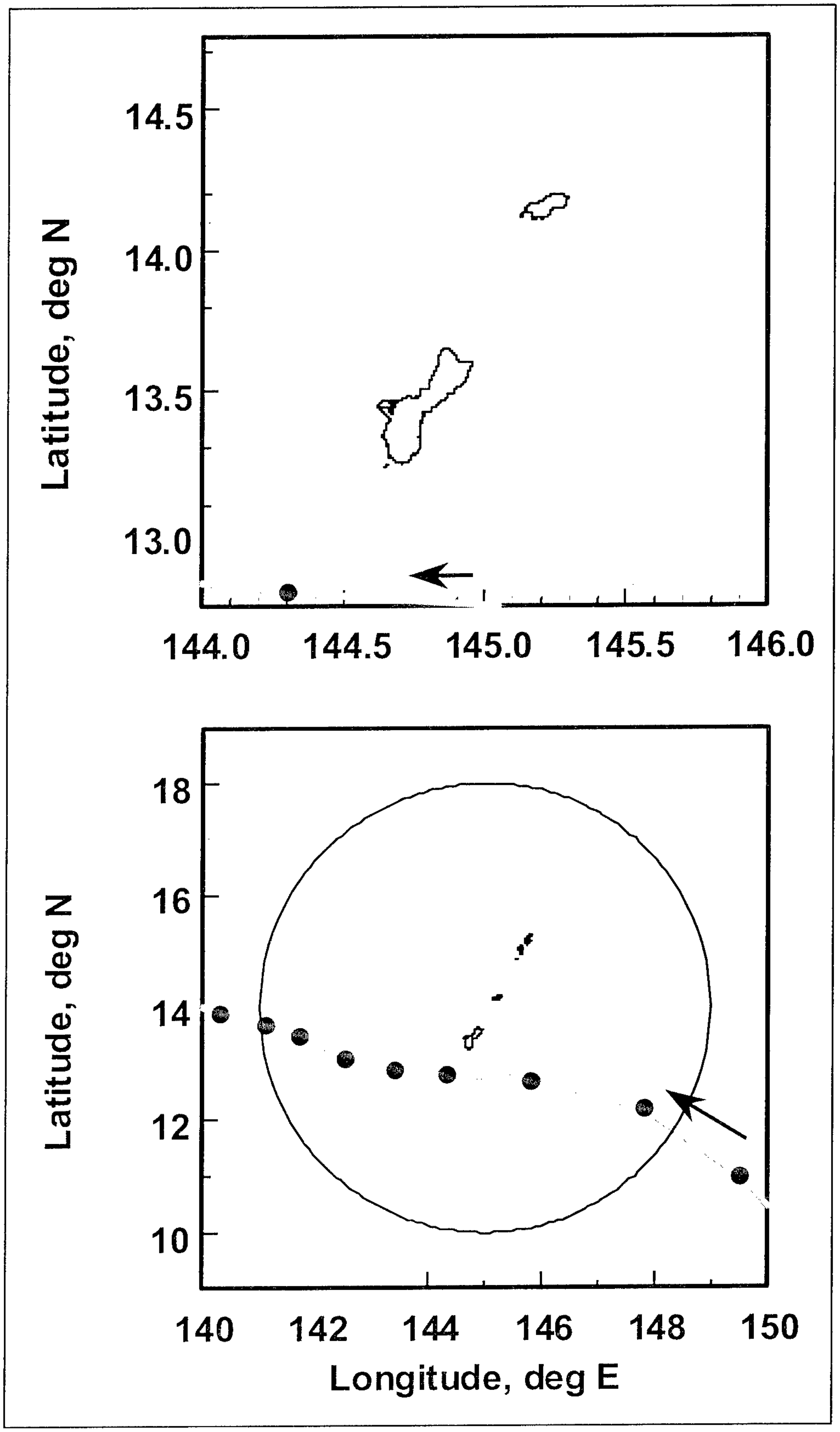


Figure A17. Storm track for Tip (2379)

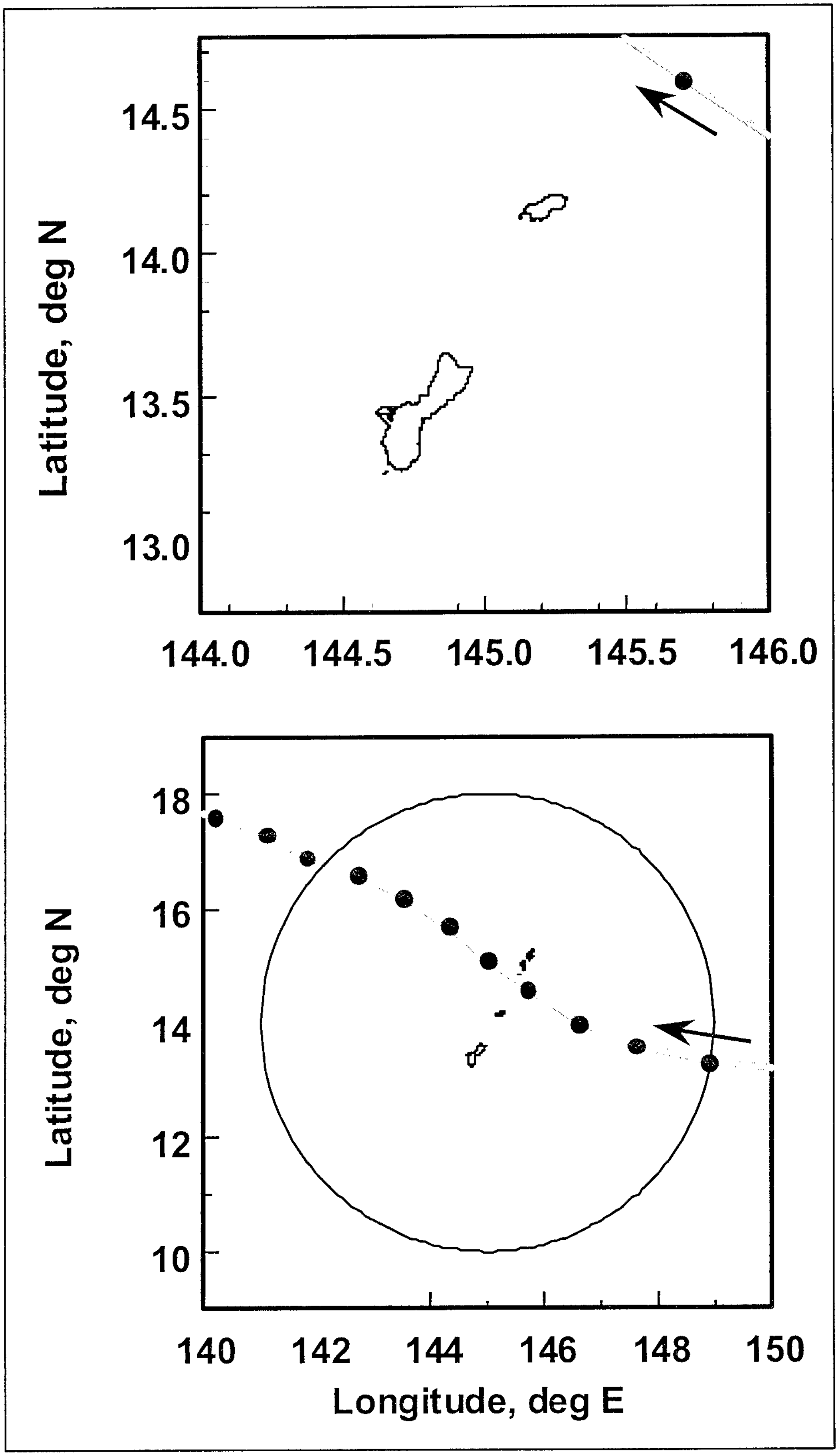


Figure A18. Storm track for Lynn (2187)

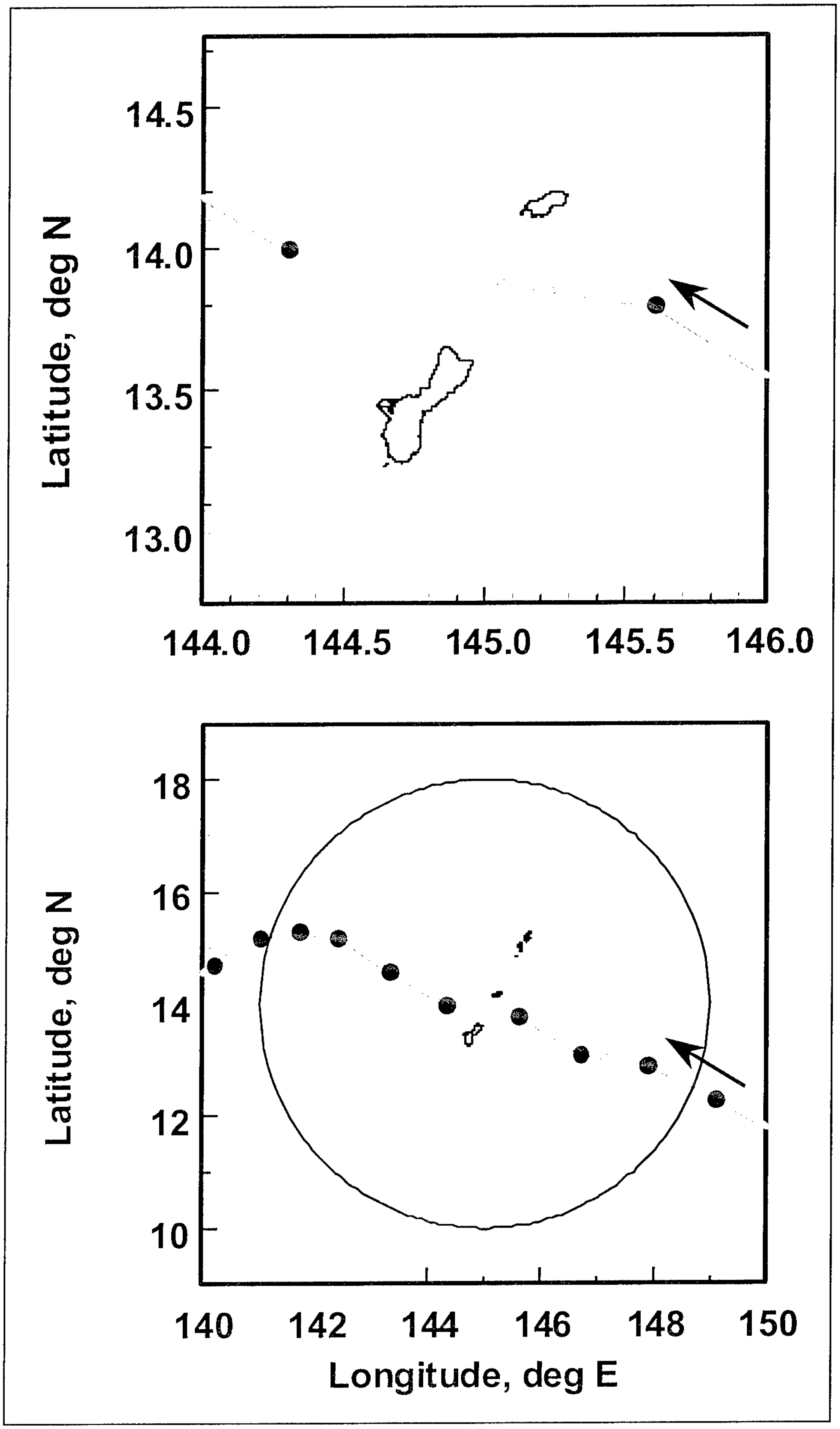


Figure A19. Storm track for Roy (0188)

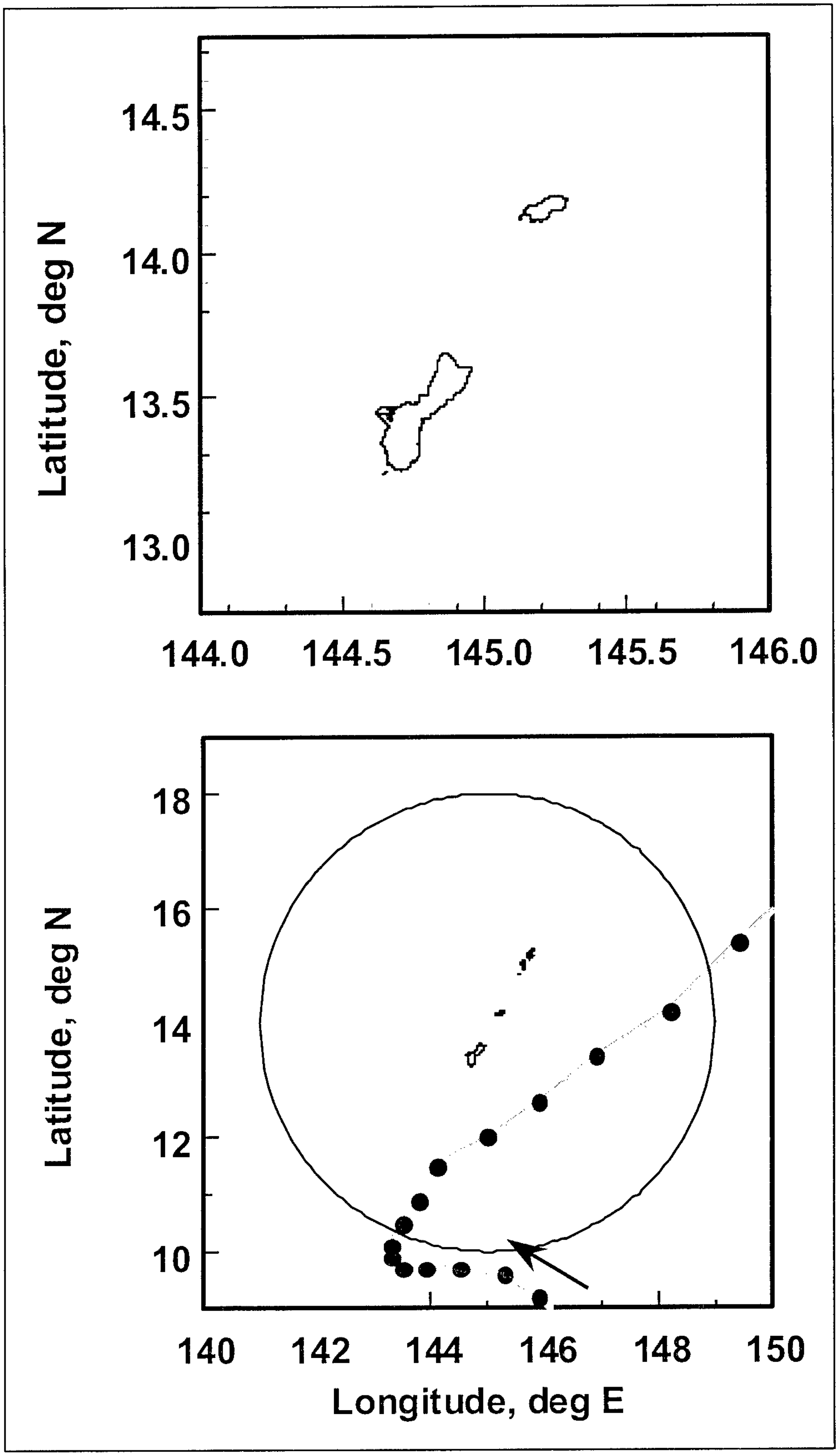


Figure A20. Storm track for Andy (0289)

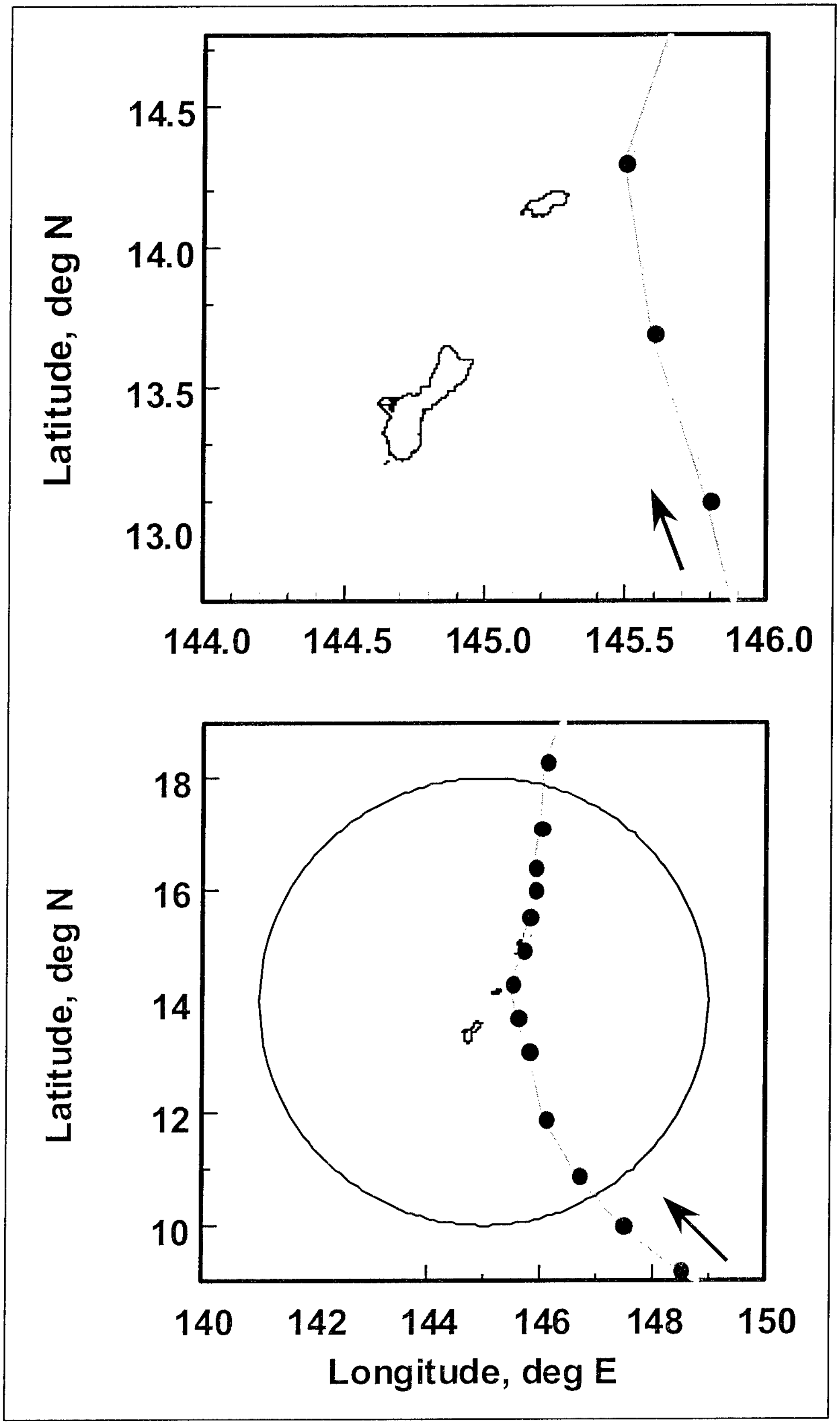


Figure A21. Storm track for Koryn (0190)

NOAA Chart #81063. Bathymetry around Guam was supplemented using NOAA Chart #81048. Grid depths are referenced to mean sea level (msl).

Tidal elevations specified at the open-water boundary were calculated from tidal amplitudes and phases contained in the LeProvost World Tidal Constituent Database, which provides constituent data at 1-deg increments in latitude and longitude. A bilinear interpolation algorithm was applied to calculate tidal amplitudes and phases at 118 open boundary nodes. The six tidal constituents applied at the open boundaries were: M_2, S_2, N_2, P_1, O_1, and K_1.

Wave and Wave Transformation Models

Deepwater wave fields were calculated by application of the Wave Information Studies Wave (WISWAVE) model (Hubertz 1992; Resio and Perrie 1989). This model is a second-generation discrete directional spectral wave model in which the spectral wave computations are based on the integration of energy over the discrete frequency spectrum. Model output includes time series of significant wave height, peak (dominant) or mean wave period, and mean wave direction. Peak period is defined as the period associated with the mid-band frequency, or that frequency band containing the largest spectral energy density. Mean wave period is an energy-weighted quantity integrated over all user-specified frequencies of interest. Model input includes a rectilinear computational grid, with water depths specified at each node, and wind speed and direction over the grid domain.

Application of the wave model required a grid resolution such that calculation points could be distributed around and near to the coasts of Rota and Guam so that representative wave conditions would be captured for all sides of the islands needed in the studies. To meet this requirement, a grid with constant spacing of 0.083 deg was developed. For wave modeling at this scale, deep water can be applied over the grid. The islands of Rota and Guam were specified as land in the grid for accurate calculation of wave sheltering and refraction. At this grid scale, Rota is represented by 6 land points and Guam by 22 land points. Details of the grid are given in Table 4.

Table 4
WISWAVE Grid Parameters

Parameter	Value
Longitude limits	141.0333 E , 149.0333 E
Latitude limits	10.0333 N, 18.0333 N
Cell side length	0.083 deg
Total number of nodes	9409
Number of nodes in north-south direction	97
Number of nodes in east-west direction	97

Wind forcing for the wave model was calculated by application of the PBL model, as discussed previously. Wind speed and direction were calculated for each point on the wave grid at 1-hr intervals.

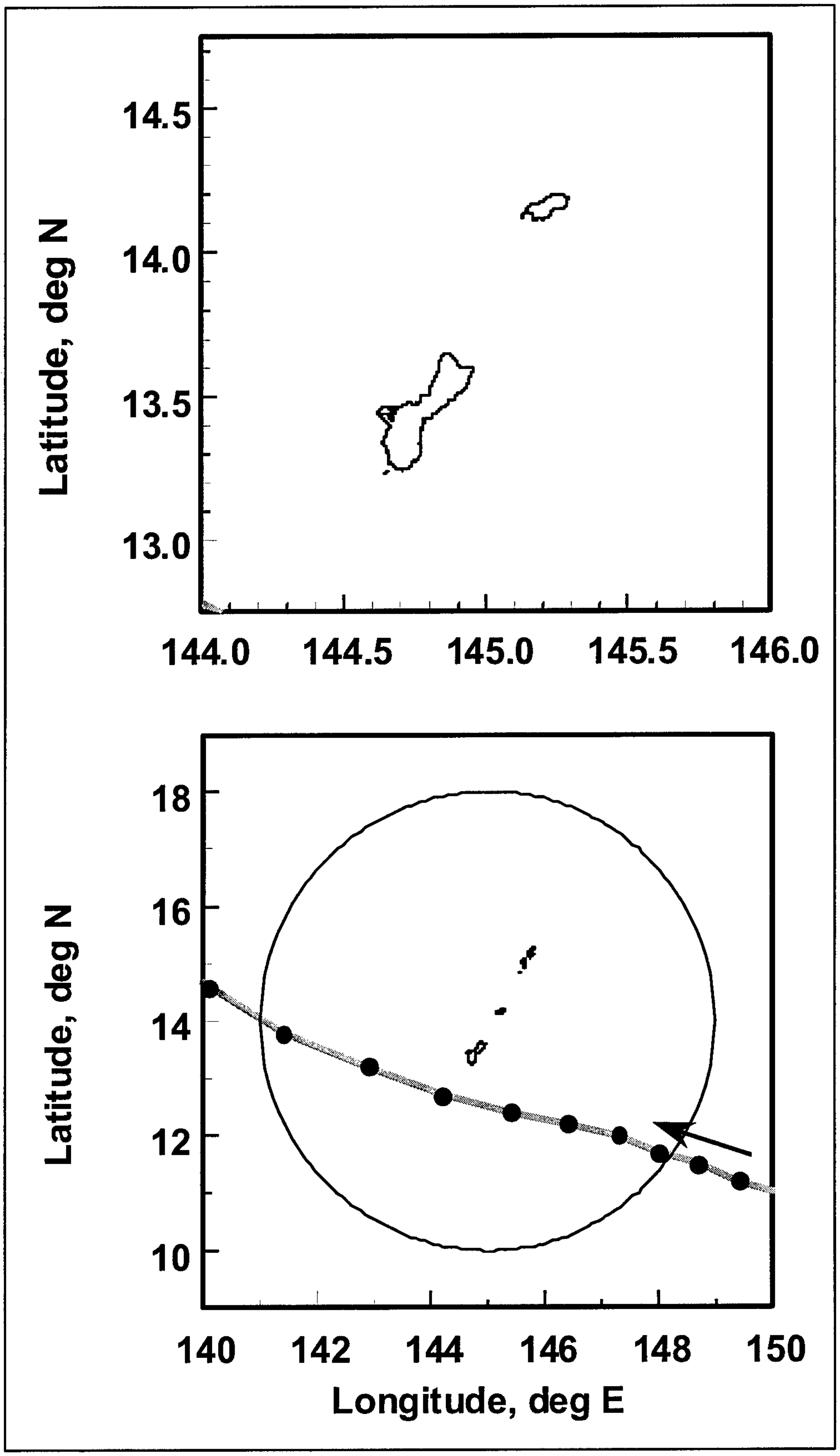


Figure A22. Storm track for Russ (3190)

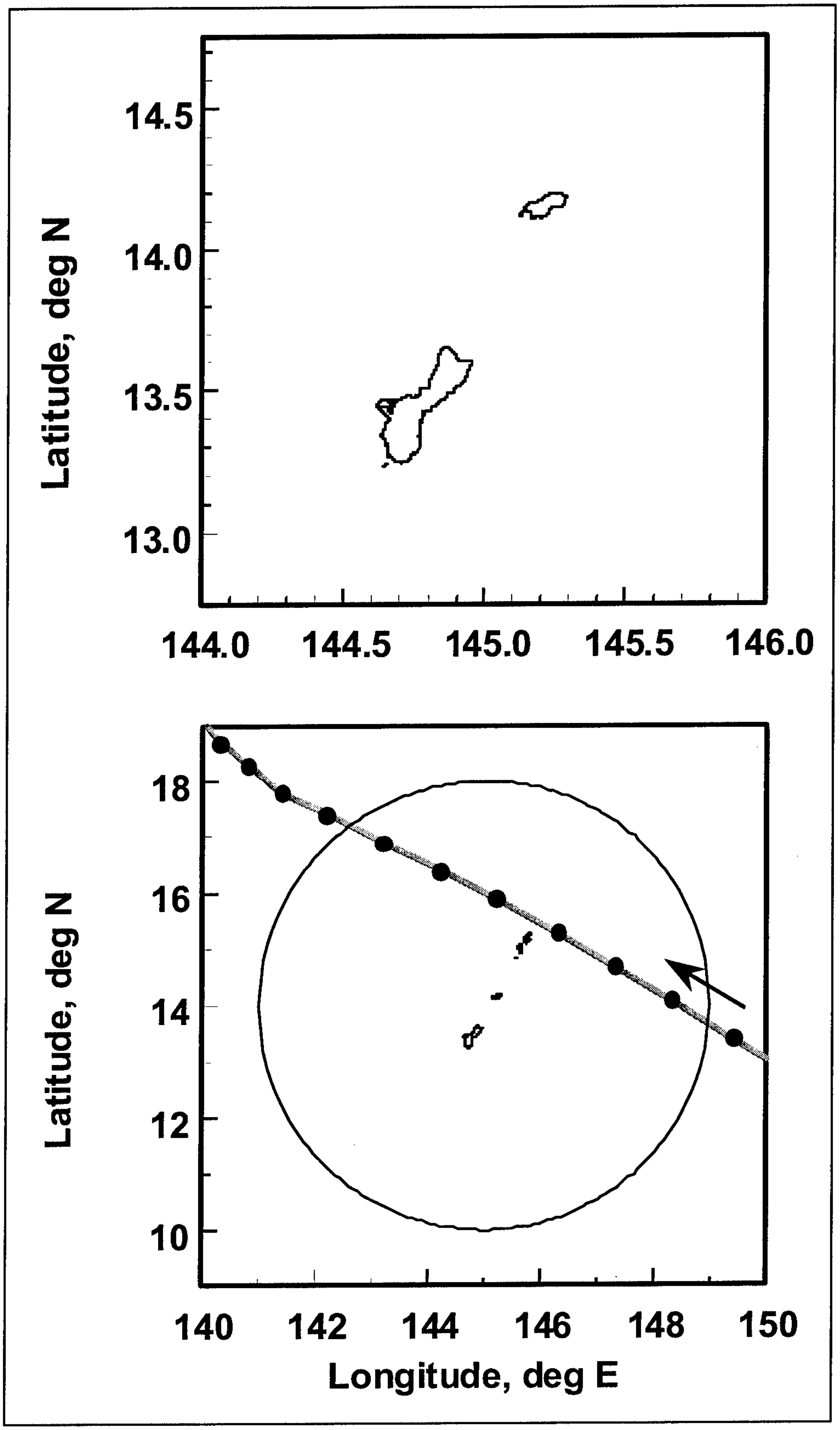


Figure A23. Storm track for Seth (2691)

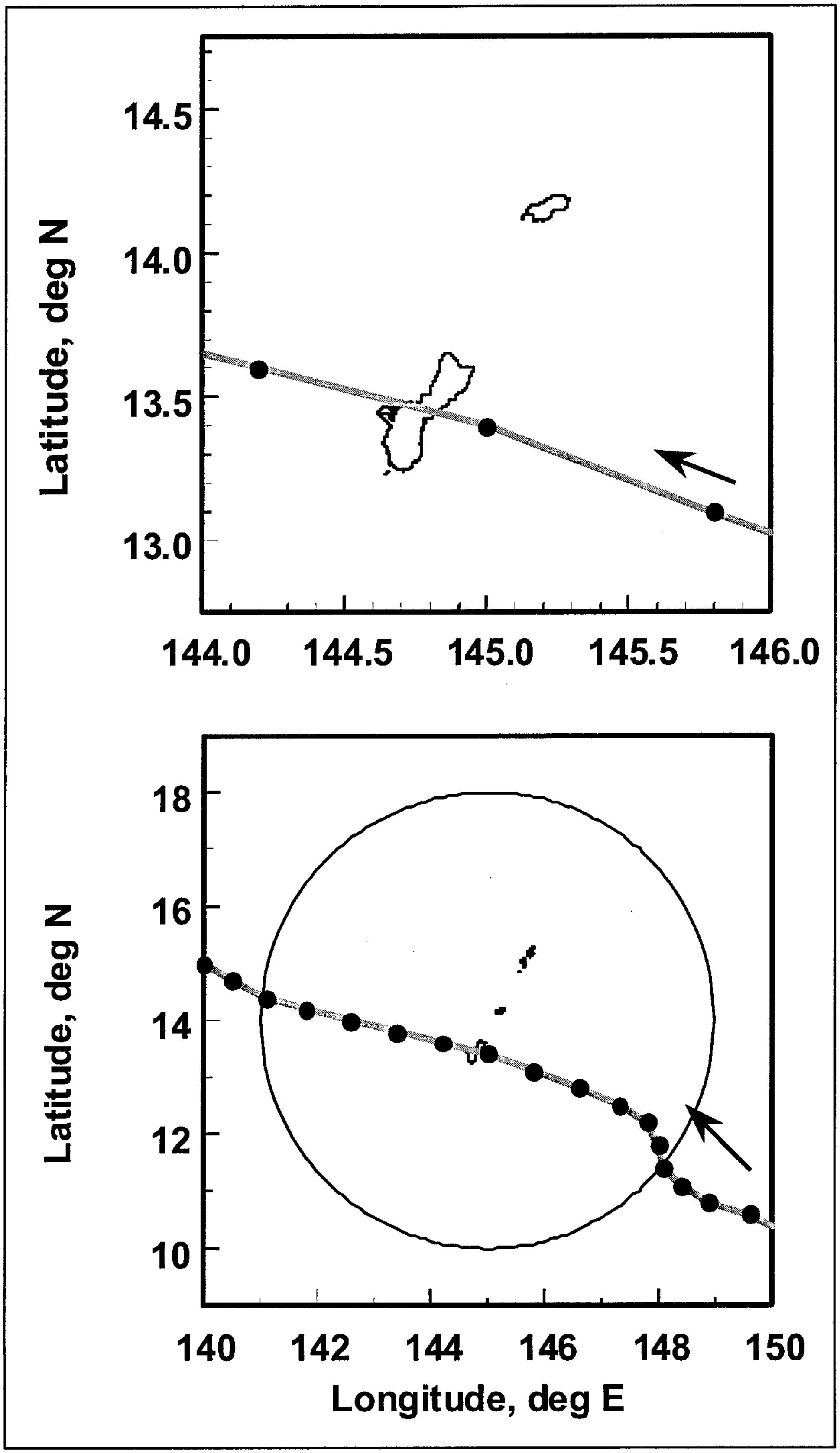


Figure A24. Storm track for Omar (1592)

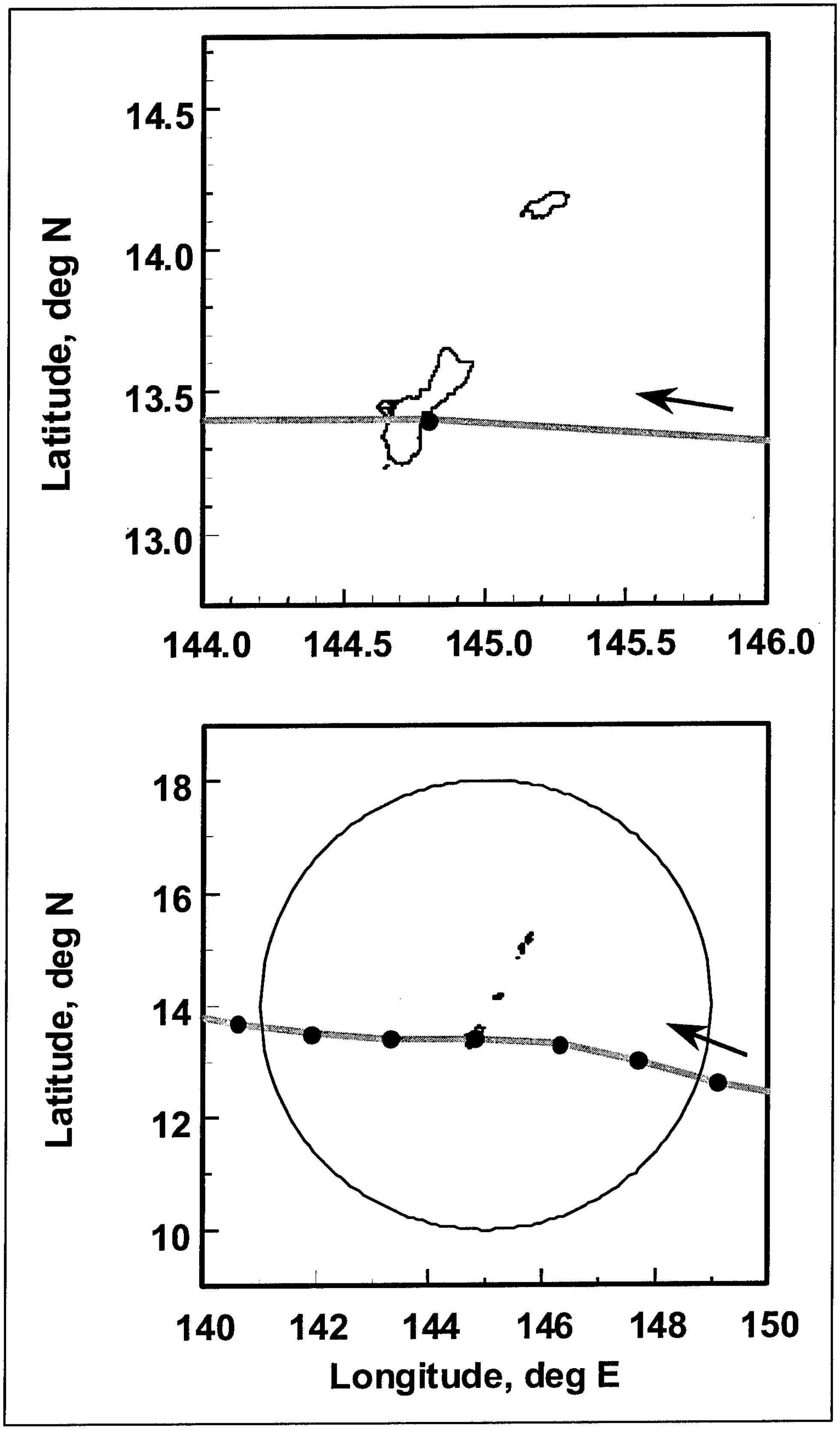


Figure A25. Storm track for Gay (3192)

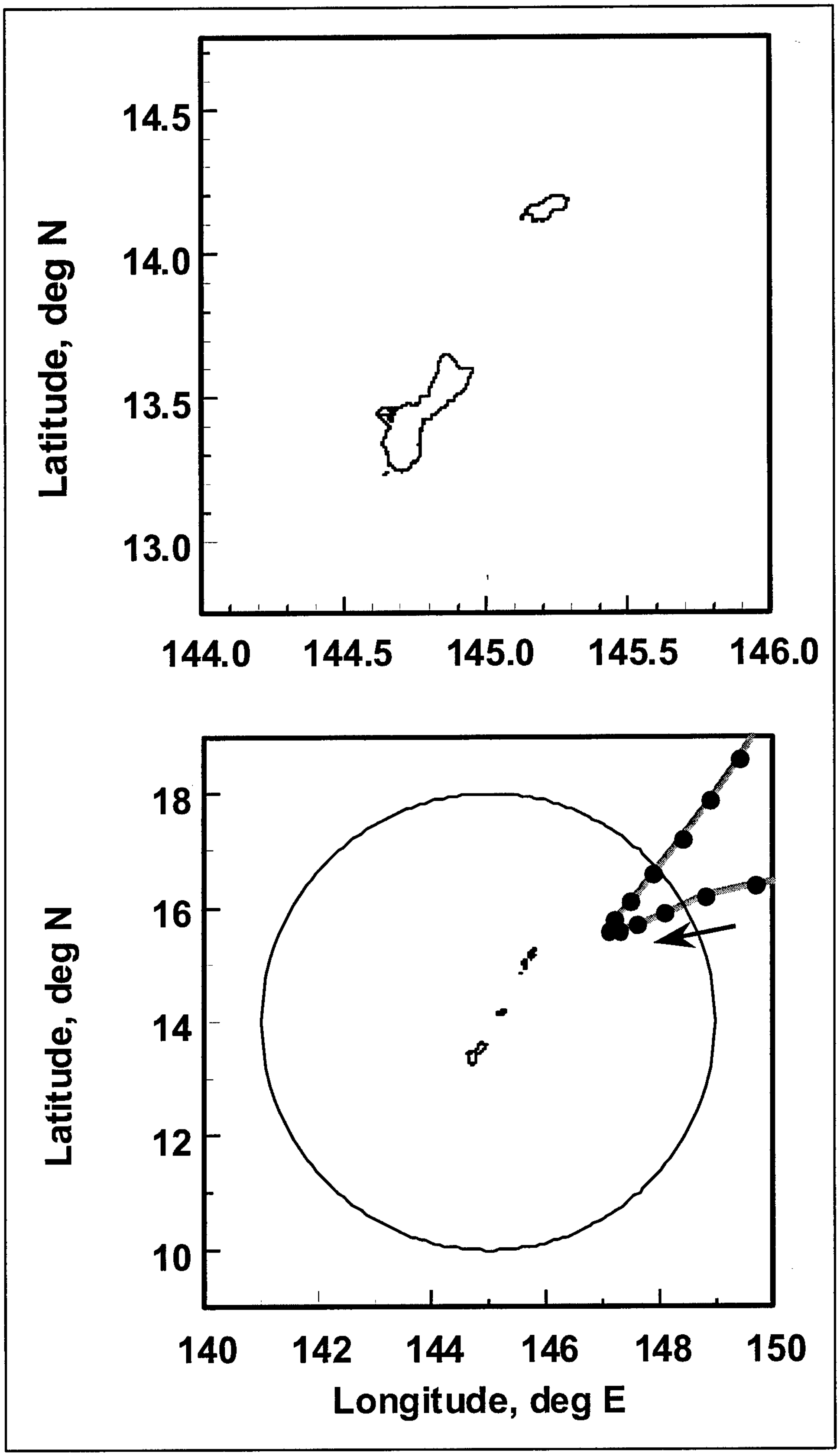


Figure A26. Storm track for Wilda (3594)

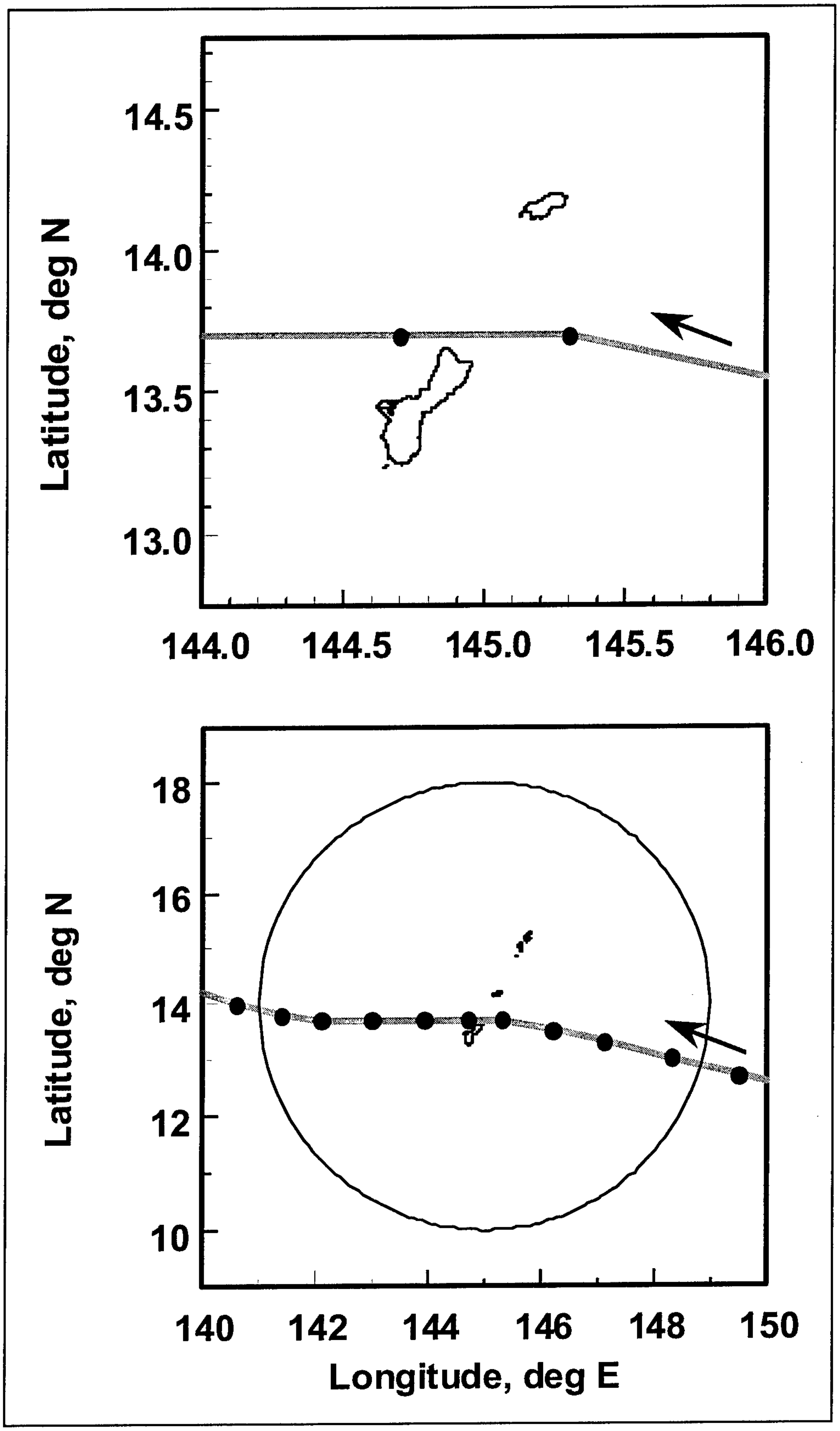


Figure A27. Storm track for Paka (0597)

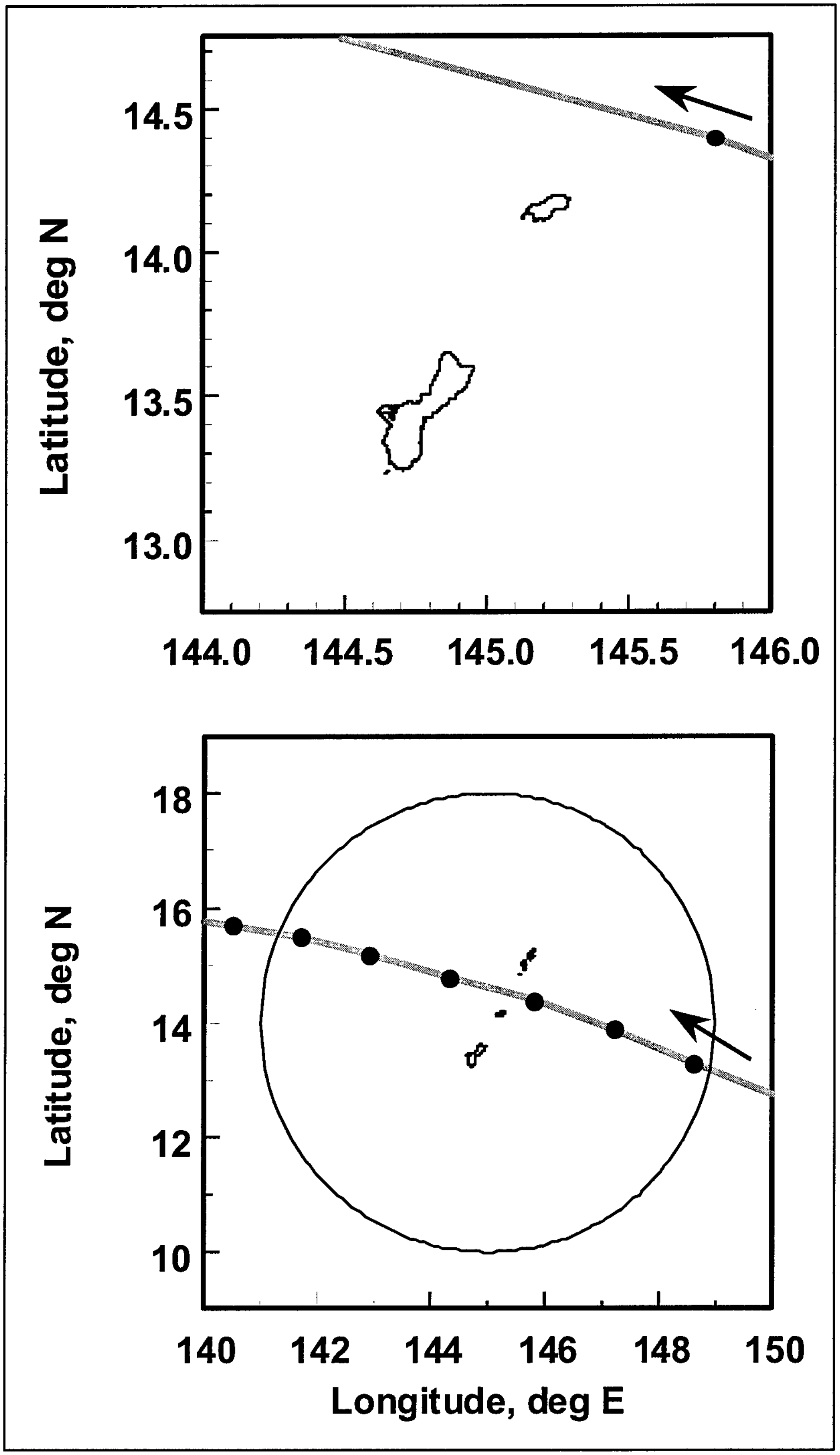


Figure A28. Storm track for Keith (2997)

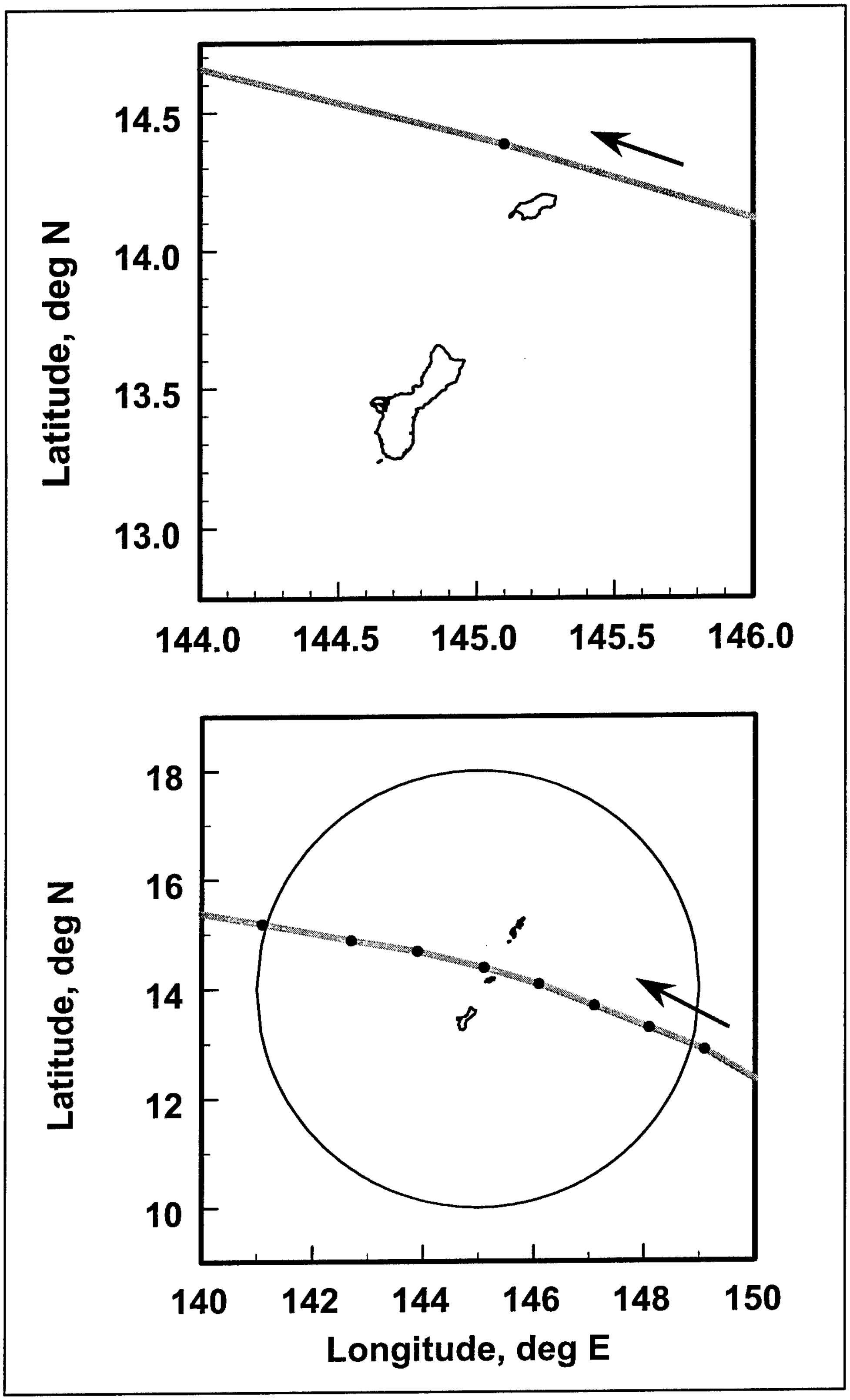


Figure A29. Storm track for hypothetical storm 1367

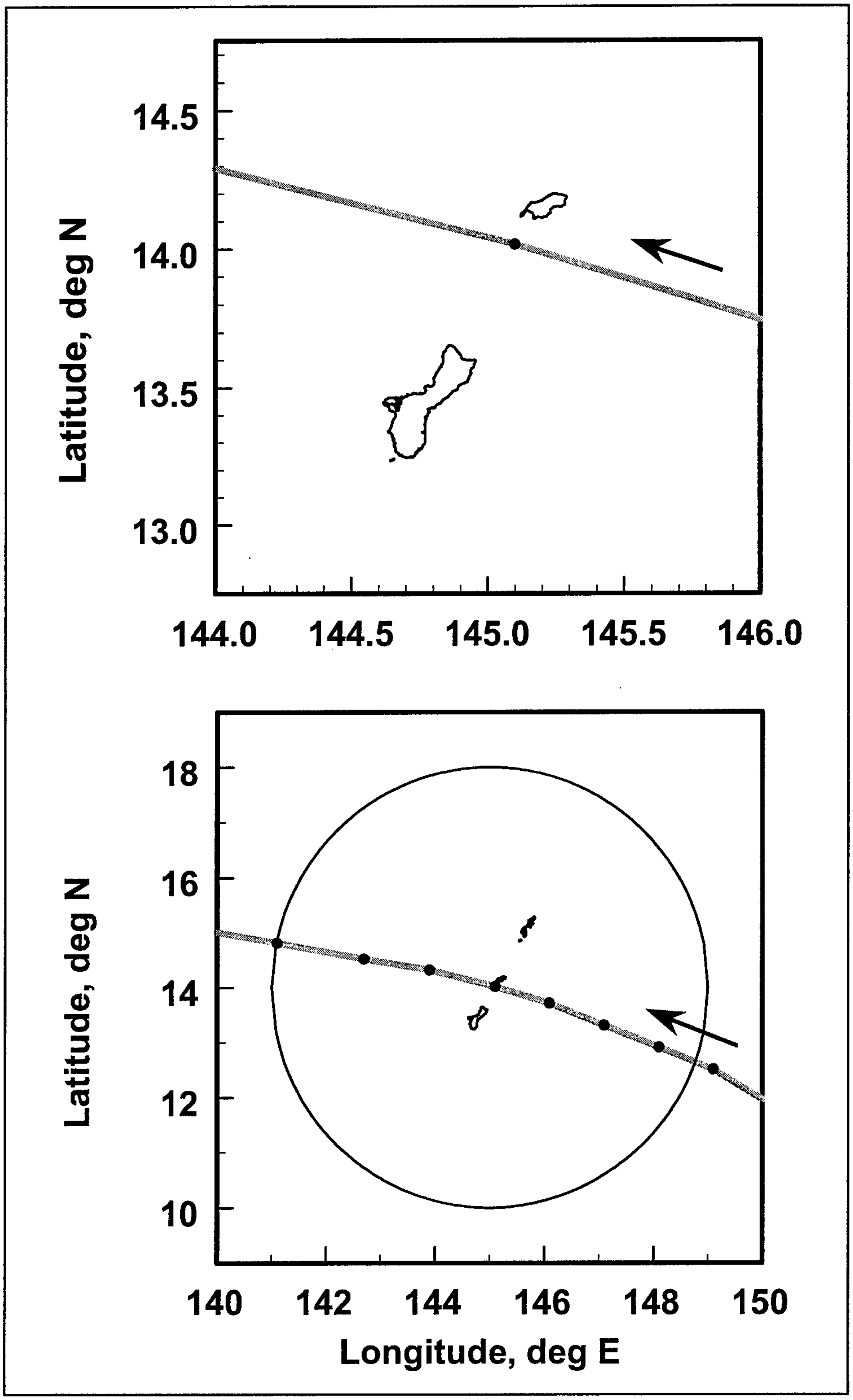


Figure A30. Storm track for hypothetical storm 4367

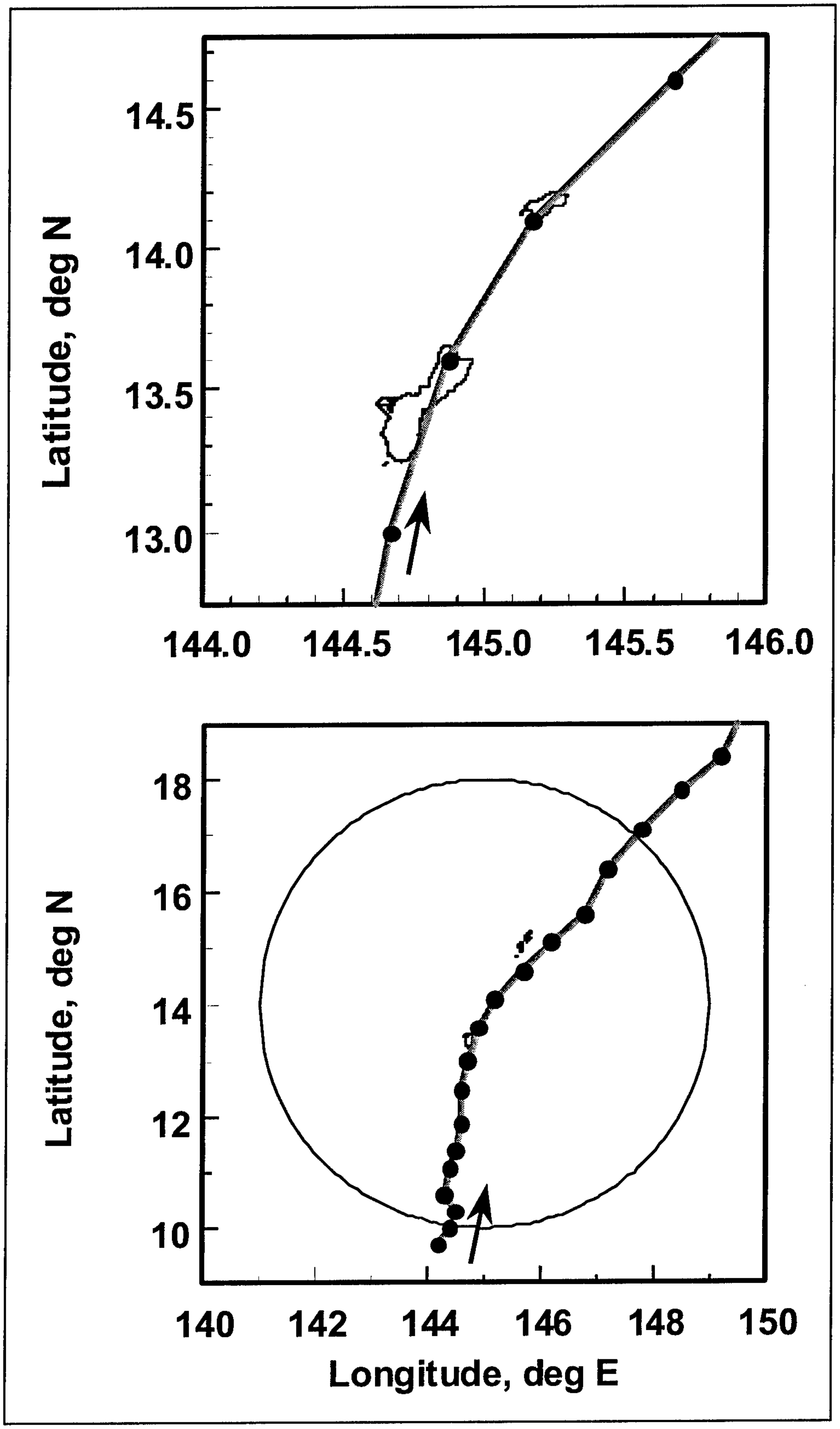


Figure A31. Storm track for hypothetical storm 5163

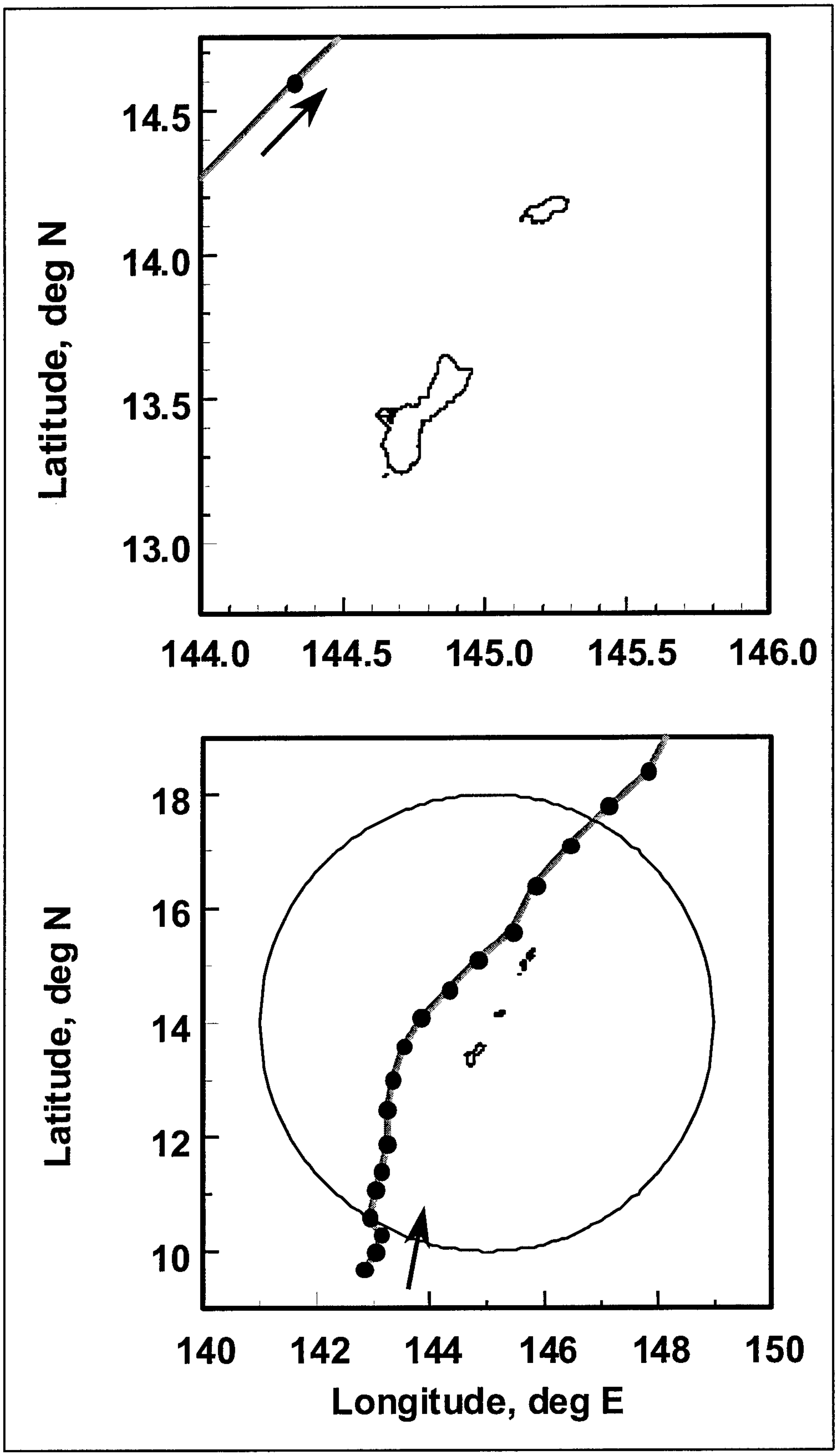


Figure A32. Storm track for hypothetical storm 6163

Appendix B
Station Locations

Table B1
Station Locations for Stage-Frequency Relationships

Station	Description or Landmark	Latitude, deg N	Longitude, deg E
R01	Apra Harbor, Guam (tide gauge)	13.4496	144.6265
Sasanhaya Embayment			
R02	Southwest end of study coast (Taipingot)	14.1269	145.1319
R03		14.1269	145.1340
R04		14.1303	145.1344
R05		14.1304	145.1365
R06		14.1327	145.1356
R07		14.1325	145.1375
R08		14.1363	145.1387
R09		14.1351	145.1407
R10	Rota village, south coast	14.1388	145.1429
R11		14.1369	145.1433
R12		14.1381	145.1466
R13		14.1360	145.1467
R14		14.1373	145.1504
R15		14.1346	145.1546
R16	Southeast end of study coast	14.1335	145.1527
Northwest and north coasts			
R17	Southwest end of study coast (Taipingot)	14.1305	145.1262
R18	Anjota Island, south end	14.1328	145.1261
R19		14.1340	145.1255
R20	Rota coast in lee of Anjota Island	14.1332	145.1306
R21	Anjota Island, north end	14.1353	145.1289
R22		14.1357	145.1330
R23		14.1482	145.1307

(Continued)

Table B1 (Concluded)			
R24		14.1379	145.1359
R25	Rota village	14.1411	145.1381
R26		14.1440	145.1375
R27	Rota village	14.1438	145.1409
R28		14.1472	145.1422
R29		14.1505	145.1438
R30		14.1519	145.1420
R31		14.1539	145.1469
R32		14.1590	145.1516
R33		14.1597	145.1500
R34		14.1634	145.1566
R35	Tataacho Point	14.1679	145.1583
R36		14.1680	145.1647
R37		14.1695	145.1652
R38		14.1671	145.1715
R39		14.1689	145.1788
R40		14.1709	145.1847
R41		14.1729	145.1845
R42		14.1732	145.1896
R43		14.1736	145.1950
R44		14.1760	145.1950
R45	Northeast end of study coast	14.1754	145.1995

Appendix C
Profile Locations Keyed To Station Locations

Table C1
Profile Locations Keyed To Station Locations

Profile	Station	Profile	Station	Profile	Station
1	R02	30	R28	59	R38
2	R02/R04	31	R28/R29	60	R38
3	R04	32	R29	61	R38/R39
4	R06	33	R29/R31	62	R38/R39
5	R06	34	R29/R31	63	R39
6	R06/R08	35	R31	64	R39
7	R06/R08	36	R31	65	R39
8	R08	37	R31/R32	66	R39
9	R08	38	R31/R32	67	R39/R40
10	R10	39	R31/R32	68	R39/R40
11	R10	40	R32	69	R39/R40
12	R12	41	R32	70	R40
13	R12	42	R32	71	R40/R42
14	R12	43	R32/R34	72	R40/R42
15	R17	44	R32/R34	73	R40/R42
16	R17	45	R32/R34	74	R42
17	R17	46	R34	75	R42
18	R20	47	R34	76	R42/R43
19	R20	48	R34/R35	77	R42/R43
20	R22	49	R35	78	R43
21	R22	50	R35/R36	79	R43
22	R24	51	R35/R36	80	R43/R45
23	R24	52	R35/R36	81	R43/R45
24	R24	53	R36	82	R45
25	R25	54	R36	83	R45
26	R27	55	R36	84	R45
27	R27	56	R36/R38	85	R45
28	R27	57	R36/R38	86	R45
29	R28	58	R36/R38	87	R45

Appendix D Stage-Frequency Relationship Tables

This appendix contains stage-frequency relationship values for profiles along the Rota coast. Maximum water level (including storm surge, wave ponding on the reef, and wave runup) and its standard deviation are given for eight return intervals for each profile. Maximum water level for Profiles 5 through 9 includes fictitious runup on an imaginary extension of the actual low bluff face, to be used subsequently with a low bluff methodology in mapping flood limits.

The tables also include maximum still water level (including storm surge, wave ponding on the reef, and nearshore wave setup) and its standard deviation for each profile and return interval. The reference datum is msl.

Table D1
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 1

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	19.7	8.9	3.6	1.6
5	41.7	1.2	7.5	0.5
10	48.5	2.8	9.1	0.6
25	56.5	3.7	10.7	0.7
50	63.5	5.9	11.8	0.9
75	67.6	6.1	12.4	0.9
100	69.7	6.8	12.7	1.1
500	77.5	8.4	13.9	1.3

Table D2
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 2

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	18.9	8.2	3.6	1.6
5	38.7	1.5	7.6	0.4
10	46.7	3.1	9.2	0.6
25	54.4	3.5	10.7	0.7
50	61.3	6.0	11.8	0.9
75	65.6	6.1	12.4	0.9
100	67.7	6.7	12.7	1.1
500	75.5	8.3	13.9	1.3

Table D3
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 3

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	11.9	4.6	3.6	1.6
5	24.7	1.1	7.6	0.5
10	30.4	2.1	9.2	0.6
25	35.9	2.2	10.8	0.7
50	40.6	4.2	12.0	1.0
75	43.0	4.6	12.6	1.0
100	44.3	5.1	12.9	1.1
500	49.5	6.4	14.2	1.4

Table D4
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 4

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	20.1	6.9	3.6	1.6
5	33.9	0.5	7.4	0.4
10	36.8	1.2	9.1	0.6
25	40.0	1.5	10.7	0.6
50	43.1	2.7	11.7	0.9
75	44.9	2.7	12.3	0.9
100	45.9	3.0	12.6	1.0
500	49.3	3.7	13.8	1.3

Table D5
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 5

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	30.3	12.0	3.7	1.6
5	56.3	1.2	7.6	0.4
10	63.3	2.8	9.2	0.6
25	70.3	4.0	10.9	0.6
50	78.9	7.3	11.9	0.9
75	84.0	7.3	12.6	0.9
100	86.5	8.0	12.9	1.0
500	95.8	9.9	14.0	1.3

Table D6
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 6

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	31.3	10.2	3.8	1.6
5	55.8	1.4	7.9	0.4
10	63.0	2.8	9.5	0.7
25	70.9	4.4	11.3	0.7
50	79.3	7.2	12.4	0.9
75	84.1	7.4	13.0	0.9
100	86.5	8.2	13.3	1.0
500	95.9	10.1	14.5	1.3

Table D7
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 7

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	31.2	10.6	3.7	1.5
5	55.6	1.0	7.7	0.4
10	61.6	2.7	9.2	0.7
25	69.9	3.9	11.1	0.7
50	78.7	7.5	12.3	0.9
75	83.8	8.4	12.9	1.0
100	86.4	9.6	13.2	1.1
500	96.1	11.9	14.4	1.3

Table D8
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 8

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	30.2	11.2	3.5	1.5
5	56.4	0.9	7.6	0.3
10	61.0	2.5	9.0	0.7
25	70.2	4.1	10.9	0.7
50	79.0	7.2	12.0	0.8
75	84.0	8.1	12.5	0.9
100	86.4	9.3	12.8	1.0
500	95.8	11.5	13.9	1.2

Table D9

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 9

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	17.6	6.0	3.4	1.4
5	32.6	0.5	7.6	0.4
10	35.8	1.9	9.1	0.6
25	41.8	2.5	10.8	0.7
50	46.9	4.3	11.8	0.8
75	49.9	4.7	12.4	0.8
100	51.4	5.4	12.7	1.0
500	56.8	6.6	13.7	1.2

Table D10

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 10

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	10.9	3.7	3.3	1.3
5	17.9	0.3	7.6	0.4
10	18.9	0.5	8.7	0.5
25	21.4	1.4	10.4	0.8
50	23.6	1.8	11.3	0.6
75	24.9	2.0	11.8	0.7
100	25.5	2.3	12.0	0.8
500	27.9	2.8	12.9	1.0

Table D11

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 11

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	15.7	4.9	3.3	1.3
5	24.0	0.2	7.6	0.4
10	25.0	0.7	8.7	0.5
25	29.0	1.7	10.4	0.7
50	31.4	1.7	11.3	0.6
75	32.7	1.9	11.7	0.7
100	33.3	2.2	12.0	0.8
500	35.6	2.8	12.9	1.0

Table D12

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 12

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	16.6	5.2	3.6	1.3
5	25.2	0.2	8.0	0.5
10	25.9	0.3	9.2	0.4
25	26.8	0.5	10.6	0.6
50	27.7	0.7	11.5	0.7
75	28.3	1.0	12.1	0.8
100	28.6	1.3	12.4	1.0
500	29.9	1.6	13.6	1.2

Table D13
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 13

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	9.7	3.3	3.4	1.2
5	20.1	0.6	7.8	0.5
10	21.3	0.5	8.9	0.4
25	23.8	1.3	10.2	0.6
50	25.6	1.5	11.0	0.7
75	26.9	1.6	11.6	0.8
100	27.5	1.9	11.9	0.9
500	29.6	2.3	13.1	1.1

Table D14
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 14

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	17.1	5.3	3.5	1.2
5	24.9	0.3	7.8	0.5
10	25.8	0.4	9.0	0.4
25	27.2	0.8	10.3	0.6
50	28.3	0.9	11.1	0.7
75	29.1	1.0	11.6	0.8
100	29.4	1.2	11.9	1.0
500	30.8	1.5	13.2	1.2

Table D15
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 15

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	9.7	3.1	3.3	1.2
5	19.0	1.9	7.2	0.6
10	27.0	2.5	8.7	0.5
25	31.7	1.9	9.6	0.3
50	34.1	2.0	10.2	0.5
75	35.4	2.2	10.5	0.6
100	36.0	2.5	10.7	0.7
500	38.7	3.1	11.5	0.8

Table D16
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 16

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	9.1	3.1	3.3	1.2
5	18.5	1.3	7.1	0.5
10	21.0	0.5	8.6	0.4
25	22.0	0.4	9.5	0.4
50	22.7	0.5	10.0	0.4
75	23.2	0.8	10.3	0.5
100	23.4	1.0	10.4	0.6
500	24.4	1.2	11.2	0.7

Table D17
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 17

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	10.0	2.9	3.3	1.2
5	19.5	1.0	7.1	0.5
10	21.2	0.4	8.5	0.4
25	22.0	0.3	9.4	0.4
50	22.5	0.4	9.9	0.4
75	22.9	0.6	10.2	0.5
100	23.1	0.7	10.4	0.6
500	24.1	0.8	11.1	0.7

Table D18
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 18

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	11.9	4.0	3.2	1.2
5	20.8	0.3	7.0	0.5
10	21.5	0.2	8.4	0.4
25	22.2	0.3	9.3	0.3
50	22.6	0.4	9.7	0.4
75	23.0	0.7	10.0	0.4
100	23.2	0.9	10.2	0.5
500	24.8	1.1	10.8	0.6

Table D19
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 19

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	8.0	2.5	3.1	1.1
5	13.7	0.4	6.5	0.5
10	14.7	0.3	7.8	0.4
25	15.4	0.3	8.6	0.3
50	15.9	0.4	9.1	0.4
75	16.1	0.5	9.3	0.4
100	16.3	0.6	9.5	0.5
500	17.1	0.8	10.1	0.6

Table D20
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 20

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	9.4	2.1	3.2	1.1
5	13.1	0.8	6.8	0.5
10	15.6	0.8	8.3	0.5
25	16.8	0.4	9.1	0.3
50	17.4	0.6	9.5	0.4
75	17.8	0.6	9.8	0.4
100	18.1	0.8	10.0	0.5
500	18.9	0.9	10.5	0.6

Table D21
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 21

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	11.7	2.6	3.3	1.1
5	14.4	0.4	7.1	0.5
10	16.1	0.7	8.7	0.5
25	17.8	0.8	9.6	0.3
50	19.0	1.1	10.0	0.4
75	19.8	1.2	10.3	0.4
100	20.2	1.5	10.4	0.5
500	21.8	1.8	11.0	0.6

Table D22
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 22

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	8.4	2.0	3.4	1.2
5	13.3	0.8	7.3	0.6
10	15.5	0.8	8.9	0.5
25	17.1	0.6	9.7	0.3
50	18.1	0.9	10.1	0.3
75	18.8	1.0	10.4	0.4
100	19.1	1.2	10.6	0.5
500	20.4	1.5	11.1	0.6

Table D23
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 23

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	9.5	2.6	3.4	1.1
5	14.4	0.5	7.3	0.6
10	16.0	0.6	8.9	0.5
25	17.6	0.6	9.7	0.3
50	18.6	1.0	10.1	0.4
75	19.4	1.2	10.5	0.5
100	19.9	1.5	10.7	0.6
500	21.3	1.8	11.3	0.7

Table D24
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 24

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	7.9	2.3	3.4	1.2
5	14.0	0.5	7.2	0.6
10	14.8	0.2	8.9	0.6
25	15.4	0.3	10.3	0.6
50	15.9	0.5	11.3	0.9
75	16.2	0.6	12.0	1.2
100	16.4	0.6	12.4	1.5
500	17.1	0.8	13.8	1.8

Table D25

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 25

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	8.4	2.5	3.1	1.2
5	14.3	0.2	7.3	0.6
10	14.7	0.2	8.9	0.6
25	15.3	0.2	10.4	0.7
50	15.6	0.3	11.4	1.0
75	15.9	0.4	12.2	1.2
100	16.0	0.5	12.6	1.5
500	16.8	0.6	14.2	1.8

Table D26

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 26

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	10.5	3.1	3.2	1.2
5	13.9	0.2	7.6	0.6
10	14.5	0.2	9.1	0.5
25	15.1	0.4	10.2	0.4
50	15.9	0.9	10.7	0.5
75	16.6	1.3	11.1	0.6
100	17.0	1.7	11.3	0.8
500	19.1	2.1	12.3	1.0

Table D27

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 27

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	11.6	3.6	3.4	1.1
5	16.9	0.3	7.3	0.5
10	17.6	0.2	8.9	0.5
25	18.3	0.3	9.9	0.4
50	18.8	0.6	10.4	0.4
75	19.4	1.1	10.7	0.5
100	19.7	1.4	10.9	0.6
500	21.4	1.8	11.6	0.7

Table D28

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 28

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	7.8	2.6	3.4	1.2
5	14.8	0.7	7.4	0.6
10	16.8	0.6	9.0	0.5
25	18.0	0.5	10.1	0.4
50	18.7	0.5	10.6	0.4
75	19.1	0.6	10.9	0.5
100	19.3	0.8	11.0	0.6
500	20.1	0.9	11.7	0.7

Table D29
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 29

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	10.2	3.6	3.4	1.2
5	18.4	1.1	7.4	0.5
10	22.0	0.9	9.1	0.6
25	23.6	0.7	10.2	0.5
50	24.5	0.9	10.8	0.6
75	25.1	1.0	11.2	0.6
100	25.4	1.1	11.4	0.7
500	26.9	1.3	12.4	0.9

Table D30
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 30

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	8.1	2.8	3.6	1.3
5	19.1	1.8	7.8	0.6
10	23.1	0.9	9.6	0.6
25	24.1	0.4	10.7	0.5
50	24.6	0.4	11.4	0.6
75	24.9	0.5	11.8	0.7
100	25.1	0.6	12.0	0.8
500	25.9	0.7	13.1	0.9

Table D31
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 31

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	9.0	3.1	3.7	1.3
5	20.9	2.7	8.1	0.7
10	26.0	1.3	10.0	0.6
25	27.7	0.7	11.0	0.5
50	29.0	1.2	11.6	0.6
75	30.0	1.7	11.9	0.6
100	30.5	2.2	12.1	0.7
500	33.5	2.7	13.1	0.9

Table D32
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 32

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	12.5	3.9	3.8	1.3
5	22.1	2.3	8.4	0.7
10	27.5	1.5	10.3	0.6
25	29.9	1.0	11.3	0.4
50	31.2	1.2	11.8	0.4
75	32.1	1.5	12.1	0.5
100	32.5	1.8	12.2	0.5
500	34.5	2.2	12.8	0.7

Table D33

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 33

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	13.7	4.4	3.9	1.3
5	27.6	4.0	8.6	0.8
10	37.8	3.2	10.6	0.6
25	44.0	2.7	11.5	0.3
50	47.5	3.1	12.0	0.4
75	49.4	3.2	12.3	0.5
100	50.4	3.6	12.4	0.5
500	55.1	4.4	13.1	0.6

Table D34

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 34

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	16.9	4.4	3.9	1.3
5	29.5	1.9	8.7	0.8
10	35.5	2.3	10.7	0.6
25	40.3	2.1	11.6	0.4
50	42.9	2.5	12.1	0.4
75	44.4	2.5	12.4	0.5
100	45.2	2.9	12.5	0.5
500	48.9	3.5	13.2	0.7

Table D35

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 35

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	10.8	3.3	4.1	1.4
5	23.8	2.1	9.0	0.8
10	27.7	1.0	11.1	0.6
25	29.5	0.7	12.0	0.3
50	30.5	1.0	12.5	0.4
75	31.4	1.3	12.8	0.5
100	31.8	1.6	12.9	0.5
500	34.0	2.0	13.6	0.7

Table D36

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 36

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	22.6	6.3	4.1	1.4
5	38.8	3.6	9.2	0.9
10	49.9	3.7	11.3	0.6
25	56.8	2.9	12.4	0.4
50	60.8	3.6	13.0	0.6
75	63.4	3.8	13.4	0.7
100	64.8	4.4	13.7	0.8
500	70.1	5.4	14.6	1.0

Table D37
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 37

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	25.2	7.0	4.1	1.4
5	35.3	1.0	9.2	0.8
10	40.5	2.3	11.1	0.6
25	46.0	2.6	12.2	0.4
50	49.1	3.0	12.8	0.6
75	51.3	3.4	13.2	0.6
100	52.4	4.0	13.4	0.7
500	56.7	5.0	14.4	0.9

Table D38
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 38

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	18.2	5.0	4.1	1.4
5	34.7	2.6	9.2	0.8
10	43.3	2.5	11.1	0.6
25	48.9	2.3	12.3	0.4
50	52.3	3.0	13.0	0.6
75	54.5	3.3	13.4	0.7
100	55.6	3.9	13.6	0.9
500	59.7	4.9	14.6	1.1

Table D39
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 39

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	18.9	6.4	3.9	1.4
5	38.9	3.6	8.9	0.7
10	48.0	3.0	10.7	0.5
25	54.6	3.1	11.7	0.4
50	58.5	3.6	12.2	0.4
75	60.7	3.6	12.6	0.5
100	61.8	4.0	12.8	0.6
500	67.5	4.9	13.4	0.8

Table D40
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 40

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	21.5	8.4	3.7	1.4
5	52.8	4.9	8.6	0.7
10	61.9	2.2	10.3	0.5
25	66.9	2.2	11.4	0.4
50	69.9	2.9	11.9	0.4
75	71.9	3.4	12.2	0.5
100	72.9	4.0	12.4	0.6
500	79.2	5.0	13.0	0.7

Table D41
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 41

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	15.1	4.6	3.8	1.4
5	23.8	1.0	8.7	0.7
10	26.6	0.8	10.4	0.5
25	28.4	0.7	11.4	0.4
50	29.4	0.9	12.0	0.4
75	30.0	0.9	12.3	0.5
100	30.3	1.0	12.5	0.6
500	31.7	1.3	13.2	0.7

Table D42
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 42

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	16.1	5.2	3.8	1.4
5	26.6	1.3	8.7	0.7
10	29.4	0.8	10.5	0.5
25	31.0	0.7	11.5	0.4
50	31.9	0.9	12.1	0.4
75	32.6	1.2	12.4	0.5
100	33.0	1.5	12.6	0.6
500	35.2	1.8	13.3	0.8

Table D43
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 43

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	18.3	6.4	3.8	1.4
5	31.8	1.8	8.8	0.7
10	36.9	1.6	10.5	0.6
25	41.1	2.1	11.6	0.4
50	43.4	2.4	12.2	0.5
75	45.4	2.6	12.5	0.6
100	46.5	3.0	12.7	0.7
500	50.0	3.7	13.5	0.9

Table D44
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 44

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	25.8	6.7	3.8	1.4
5	36.3	2.3	8.6	0.7
10	41.3	1.5	10.5	0.6
25	44.9	1.9	11.6	0.4
50	47.0	2.1	12.1	0.5
75	48.5	2.3	12.5	0.6
100	49.3	2.6	12.7	0.7
500	52.8	3.2	13.5	0.8

Table D45

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 45

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	23.7	6.0	3.8	1.4
5	35.1	1.5	8.6	0.7
10	38.0	0.9	10.5	0.6
25	40.2	1.1	11.7	0.5
50	41.5	1.2	12.3	0.6
75	42.4	1.4	12.7	0.7
100	42.8	1.5	12.9	0.8
500	44.8	1.9	13.8	0.9

Table D46

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 46

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	10.8	4.3	3.7	1.4
5	28.1	2.5	8.4	0.7
10	32.7	0.9	10.3	0.6
25	34.8	0.9	11.4	0.4
50	36.1	1.2	12.0	0.5
75	37.0	1.5	12.4	0.8
100	37.4	1.9	12.6	0.9
500	40.3	2.3	13.8	1.2

Table D47

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 47

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	9.2	3.1	3.9	1.5
5	20.6	1.7	8.7	0.7
10	24.8	1.2	10.6	0.6
25	27.0	1.0	11.9	0.5
50	28.0	1.1	12.4	0.5
75	28.8	1.2	12.8	0.6
100	29.1	1.4	13.0	0.7
500	31.0	1.7	13.9	0.8

Table D48

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 48

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	8.3	3.0	4.0	1.3
5	21.8	2.0	8.9	0.8
10	26.2	1.1	10.9	0.6
25	28.5	0.9	12.0	0.4
50	29.9	1.3	12.6	0.6
75	30.8	1.5	13.0	0.7
100	31.3	1.7	13.3	0.9
500	33.8	2.1	14.6	1.1

Table D49

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 49

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	10.2	3.0	3.9	1.2
5	20.1	1.5	8.3	0.8
10	23.6	0.9	10.3	0.6
25	25.5	0.8	11.4	0.5
50	26.5	0.9	12.0	0.6
75	27.3	1.0	12.4	0.6
100	27.7	1.2	12.6	0.7
500	28.9	1.5	13.3	0.8

Table D50

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 50

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	12.3	3.7	4.3	1.3
5	21.9	0.9	9.0	0.8
10	24.9	1.1	11.0	0.6
25	27.5	1.1	12.2	0.5
50	28.8	1.4	12.8	0.6
75	29.9	1.4	13.2	0.6
100	30.4	1.6	13.4	0.7
500	32.3	2.0	14.3	0.8

Table D51

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 51

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	12.3	3.3	4.5	1.3
5	21.5	1.2	9.2	0.9
10	25.0	1.1	11.3	0.5
25	27.7	1.1	12.4	0.4
50	29.1	1.3	13.1	0.6
75	30.1	1.4	13.4	0.6
100	30.5	1.7	13.6	0.7
500	32.6	2.1	14.4	0.8

Table D52

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 52

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	11.7	3.1	4.6	1.4
5	22.3	1.9	9.4	1.0
10	25.9	1.0	11.4	0.6
25	28.0	0.6	12.5	0.3
50	29.0	0.9	13.0	0.5
75	29.8	1.1	13.4	0.6
100	30.2	1.4	13.7	0.8
500	31.7	1.7	14.6	0.9

Table D53

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 53

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	16.7	4.0	4.7	1.4
5	24.1	1.3	9.6	1.0
10	26.9	0.9	11.5	0.5
25	28.8	0.6	12.4	0.3
50	29.5	0.8	12.9	0.5
75	30.3	1.0	13.4	0.6
100	30.7	1.2	13.6	0.7
500	32.0	1.5	14.5	0.9

Table D54

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 54

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	15.5	3.8	4.6	1.3
5	24.0	0.9	9.3	0.9
10	26.3	0.6	11.1	0.5
25	27.8	0.5	12.0	0.3
50	28.6	0.8	12.5	0.5
75	29.2	1.0	12.9	0.6
100	29.6	1.2	13.2	0.7
500	31.2	1.5	14.0	0.9

Table D55

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 55

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	16.8	4.0	4.6	1.3
5	24.0	1.2	9.3	0.9
10	26.5	0.7	11.1	0.5
25	28.2	0.6	12.0	0.3
50	28.9	0.7	12.5	0.5
75	29.6	0.9	12.9	0.6
100	29.9	1.1	13.2	0.7
500	31.1	1.3	14.0	0.9

Table D56

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 56

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	15.6	3.7	4.7	1.4
5	22.9	2.0	9.4	0.9
10	26.4	1.0	11.3	0.5
25	28.3	0.6	12.2	0.3
50	29.1	0.8	12.8	0.5
75	29.9	1.0	13.2	0.6
100	30.2	1.2	13.4	0.7
500	31.5	1.5	14.2	0.9

Table D57
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 57

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	15.9	3.6	4.8	1.4
5	23.8	2.2	9.8	0.9
10	28.1	1.2	11.7	0.5
25	30.2	0.6	12.6	0.3
50	31.1	0.8	13.1	0.5
75	31.9	1.1	13.6	0.6
100	32.4	1.4	13.8	0.7
500	33.8	1.7	14.6	0.9

Table D58
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 58

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	11.5	3.0	5.0	1.5
5	22.9	1.8	10.2	0.9
10	26.3	0.9	12.2	0.5
25	28.0	0.6	13.1	0.4
50	28.7	0.8	13.6	0.5
75	29.5	0.9	14.0	0.6
100	29.9	1.2	14.2	0.7
500	31.2	1.5	15.1	0.9

Table D59
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 59

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	14.4	3.4	4.8	1.4
5	24.5	2.0	9.8	0.9
10	28.1	1.1	11.7	0.6
25	30.0	0.6	12.6	0.3
50	30.8	0.9	13.1	0.5
75	31.5	1.0	13.6	0.6
100	31.9	1.2	13.8	0.7
500	33.3	1.5	14.6	0.8

Table D60
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 60

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	21.6	4.9	4.4	1.3
5	31.2	1.7	9.0	0.9
10	34.6	0.8	10.9	0.5
25	36.2	0.5	11.7	0.4
50	36.9	0.8	12.3	0.6
75	37.6	0.9	12.7	0.7
100	38.0	1.1	13.0	0.8
500	39.4	1.4	14.1	1.0

Table D61
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 61

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	13.5	3.4	4.4	1.3
5	21.2	1.7	9.0	0.9
10	24.4	0.8	10.8	0.4
25	25.9	0.5	11.6	0.3
50	26.5	0.7	12.0	0.4
75	27.2	0.9	12.3	0.4
100	27.5	1.0	12.5	0.5
500	28.7	1.3	13.1	0.7

Table D62
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 62

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	14.3	3.3	4.4	1.4
5	21.1	2.2	9.0	0.9
10	25.0	1.0	10.9	0.5
25	26.3	0.4	11.8	0.3
50	26.9	0.6	12.2	0.4
75	27.5	0.8	12.6	0.5
100	27.8	1.0	12.7	0.6
500	28.9	1.3	13.4	0.7

Table D63
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 63

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	12.5	4.2	4.2	1.3
5	20.8	1.4	9.2	0.8
10	23.5	0.6	10.8	0.4
25	24.8	0.5	11.6	0.3
50	25.5	0.6	12.0	0.4
75	26.1	0.8	12.4	0.4
100	26.4	1.0	12.5	0.5
500	27.5	1.3	13.2	0.7

Table D64
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 64

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	10.6	3.0	4.4	1.4
5	19.4	2.1	9.2	0.9
10	22.8	0.9	11.1	0.5
25	24.3	0.6	12.0	0.3
50	25.3	0.7	12.4	0.4
75	26.0	0.9	12.8	0.5
100	26.3	1.1	13.0	0.6
500	27.4	1.4	13.6	0.7

Table D65

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 65

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	8.9	3.0	4.5	1.4
5	18.6	1.4	9.2	0.9
10	21.2	0.7	11.1	0.5
25	22.7	0.6	12.0	0.3
50	23.7	0.9	12.4	0.4
75	24.4	1.2	12.7	0.5
100	24.8	1.5	12.9	0.6
500	26.6	1.9	13.6	0.7

Table D66

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 66

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	11.4	3.2	4.3	1.3
5	17.9	1.5	8.7	0.9
10	20.7	0.8	10.5	0.5
25	22.1	0.5	11.3	0.3
50	22.7	0.6	11.7	0.4
75	23.3	0.8	12.0	0.4
100	23.6	1.0	12.2	0.5
500	24.6	1.2	12.8	0.7

Table D67

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 67

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	12.7	3.1	4.0	1.3
5	18.0	1.0	8.7	0.7
10	20.0	0.4	10.2	0.4
25	21.0	0.4	10.9	0.3
50	21.5	0.5	11.3	0.4
75	21.9	0.6	11.7	0.4
100	22.1	0.8	11.9	0.6
500	23.1	1.0	12.5	0.7

Table D68

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 68

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	11.6	2.9	4.2	1.3
5	18.2	1.4	8.5	0.9
10	20.7	0.6	10.3	0.5
25	21.8	0.4	11.1	0.3
50	22.4	0.6	11.5	0.4
75	22.9	0.7	11.9	0.5
100	23.1	0.9	12.0	0.5
500	24.2	1.1	12.7	0.7

Table D69

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 69

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	11.2	3.2	4.2	1.3
5	19.1	1.8	8.4	0.9
10	22.1	0.7	10.3	0.5
25	23.6	0.6	11.2	0.3
50	24.4	0.8	11.6	0.4
75	25.1	1.0	11.9	0.5
100	25.4	1.2	12.0	0.5
500	27.1	1.5	12.7	0.7

Table D70

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 70

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	10.8	3.0	4.4	1.3
5	19.2	1.9	8.9	1.0
10	22.3	0.8	10.9	0.6
25	23.3	0.4	11.8	0.3
50	23.9	0.6	12.3	0.4
75	24.5	0.9	12.6	0.5
100	24.8	1.1	12.8	0.6
500	26.2	1.3	13.6	0.8

Table D71

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 71

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	9.9	2.8	4.2	1.3
5	18.3	1.6	8.5	0.9
10	21.1	0.7	10.5	0.5
25	22.4	0.4	11.4	0.3
50	23.0	0.7	11.8	0.4
75	23.6	0.8	12.1	0.4
100	23.9	1.0	12.3	0.5
500	25.2	1.2	13.0	0.6

Table D72

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 72

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	9.4	2.4	4.0	1.2
5	15.2	1.1	8.1	0.9
10	17.2	0.5	9.8	0.5
25	18.2	0.3	10.7	0.3
50	18.6	0.4	11.1	0.4
75	19.0	0.5	11.5	0.4
100	19.2	0.6	11.7	0.5
500	19.9	0.8	12.3	0.6

Table D73

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 73

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	9.7	2.4	4.1	1.3
5	13.0	0.2	8.3	0.9
10	13.6	0.3	10.2	0.5
25	14.3	0.3	11.1	0.4
50	14.8	0.4	11.6	0.4
75	15.2	0.5	11.9	0.5
100	15.4	0.6	12.1	0.6
500	16.0	0.8	12.8	0.7

Table D74

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 74

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	9.0	2.1	4.1	1.2
5	13.3	0.7	8.1	0.8
10	14.6	0.3	10.0	0.5
25	15.1	0.3	10.9	0.4
50	15.4	0.2	11.5	0.5
75	15.6	0.2	11.8	0.6
100	15.6	0.3	12.0	0.6
500	16.0	0.3	12.8	0.8

Table D75

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 75

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	9.6	2.4	4.0	1.2
5	16.4	1.2	8.1	0.8
10	18.6	0.5	9.9	0.4
25	19.5	0.4	10.8	0.3
50	20.0	0.5	11.2	0.4
75	20.4	0.5	11.6	0.5
100	20.6	0.6	11.7	0.6
500	21.3	0.7	12.4	0.7

Table D76

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 76

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	12.4	3.2	4.0	1.3
5	17.5	0.4	8.5	0.8
10	18.7	0.4	10.1	0.4
25	19.7	0.4	11.0	0.3
50	20.3	0.5	11.5	0.5
75	20.8	0.6	11.9	0.6
100	21.0	0.8	12.1	0.7
500	21.9	1.0	12.9	0.8

Table D77

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 77

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	8.7	2.3	4.0	1.2
5	15.1	1.4	8.5	0.9
10	18.6	1.0	10.4	0.6
25	20.3	0.6	11.3	0.3
50	21.1	0.7	11.7	0.4
75	21.7	0.9	12.0	0.4
100	22.1	1.1	12.1	0.5
500	23.3	1.4	12.9	0.6

Table D78

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 78

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	11.5	2.9	4.1	1.3
5	18.4	1.7	8.8	0.9
10	22.4	1.1	10.7	0.6
25	24.1	0.5	11.6	0.3
50	24.8	0.6	12.0	0.4
75	25.4	0.8	12.3	0.4
100	25.7	1.0	12.5	0.5
500	26.9	1.2	13.2	0.6

Table D79

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 79

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	12.1	3.0	4.1	1.3
5	18.9	1.7	8.8	0.9
10	22.9	1.1	10.7	0.6
25	24.5	0.5	11.5	0.3
50	25.2	0.6	12.0	0.4
75	25.8	0.8	12.3	0.4
100	26.1	1.0	12.4	0.5
500	27.4	1.2	13.1	0.6

Table D80

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 80

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	12.7	3.0	4.2	1.3
5	19.8	1.6	9.1	0.9
10	24.0	1.2	11.2	0.6
25	26.0	0.7	12.1	0.3
50	27.1	0.9	12.5	0.4
75	27.8	1.0	12.8	0.5
100	28.2	1.3	13.0	0.6
500	29.5	1.6	13.7	0.7

Table D81

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 81

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	12.3	3.0	4.2	1.3
5	19.5	1.6	9.0	0.9
10	22.9	0.9	11.0	0.6
25	24.2	0.5	11.9	0.4
50	24.8	0.6	12.3	0.4
75	25.3	0.7	12.6	0.5
100	25.5	0.8	12.8	0.6
500	26.5	1.0	13.5	0.7

Table D82

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 82

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	14.0	3.7	4.1	1.3
5	20.5	1.9	8.9	0.9
10	24.8	1.2	10.9	0.6
25	26.4	0.6	11.8	0.3
50	27.2	0.8	12.2	0.4
75	27.8	0.9	12.6	0.5
100	28.1	1.0	12.7	0.5
500	29.4	1.3	13.4	0.7

Table D83

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 83

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	14.6	4.0	4.1	1.3
5	22.2	1.5	8.9	0.8
10	25.8	1.0	11.0	0.6
25	27.8	0.9	12.0	0.3
50	29.0	1.0	12.5	0.5
75	29.8	1.2	12.9	0.6
100	30.2	1.5	13.0	0.6
500	32.0	1.8	13.9	0.8

Table D84

Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 84

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	13.1	3.8	4.1	1.3
5	21.2	1.5	8.8	0.8
10	25.2	1.0	10.8	0.5
25	26.7	0.6	11.7	0.3
50	27.5	0.7	12.1	0.4
75	28.0	0.7	12.4	0.4
100	28.3	0.8	12.5	0.4
500	29.3	1.0	13.1	0.6

Table D85
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 85

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	14.1	4.2	4.0	1.3
5	29.7	2.1	8.8	0.8
10	34.0	1.1	10.8	0.5
25	35.8	0.7	11.6	0.3
50	36.9	0.9	12.0	0.3
75	37.8	1.5	12.2	0.4
100	38.3	2.0	12.4	0.5
500	40.2	2.5	12.9	0.6

Table D86
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 86

Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	14.1	3.8	4.2	1.3
5	22.6	1.7	9.1	0.9
10	26.5	1.0	11.2	0.6
25	27.9	0.5	12.1	0.4
50	28.6	0.7	12.5	0.4
75	29.0	0.7	12.8	0.5
100	29.3	0.8	13.0	0.6
500	30.4	1.0	13.8	0.7

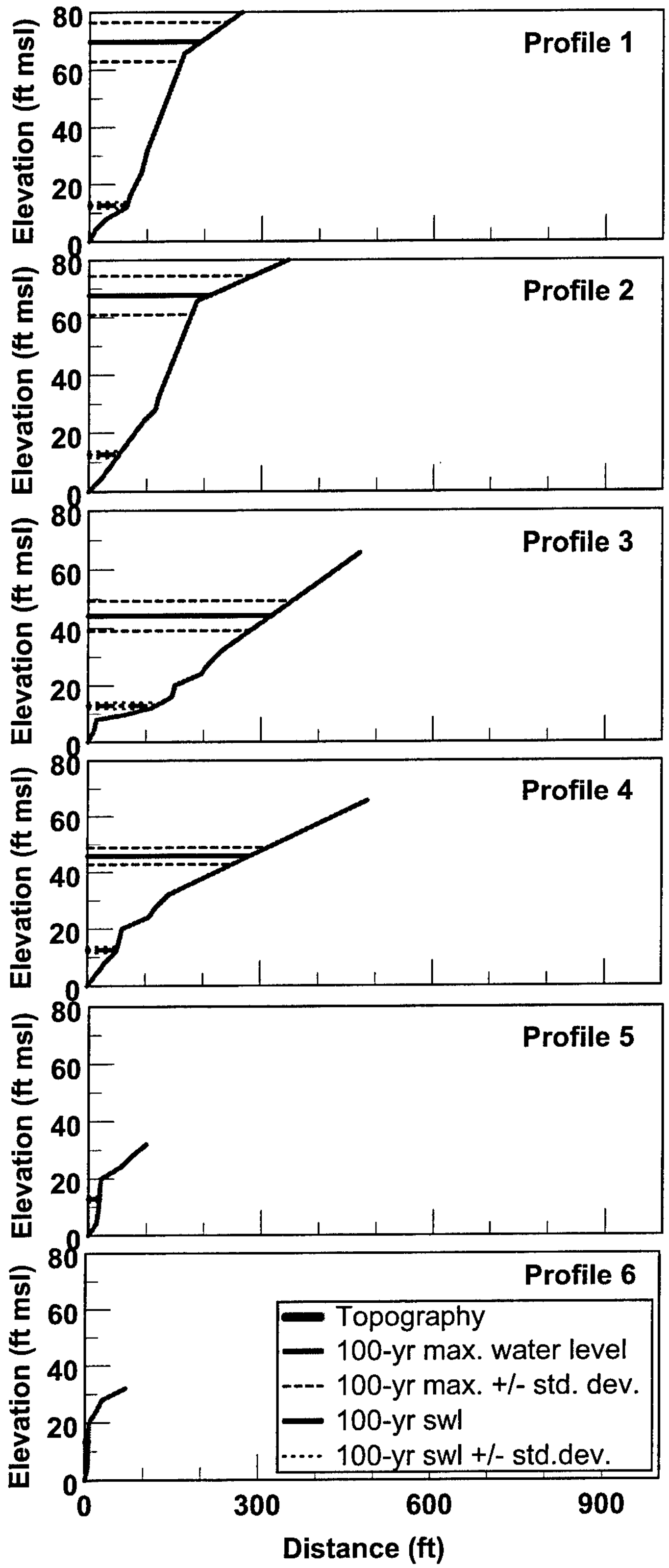
Table D87
Return Period, Maximum Water Level, and Water Level Standard Deviation for Profile: Rota 87

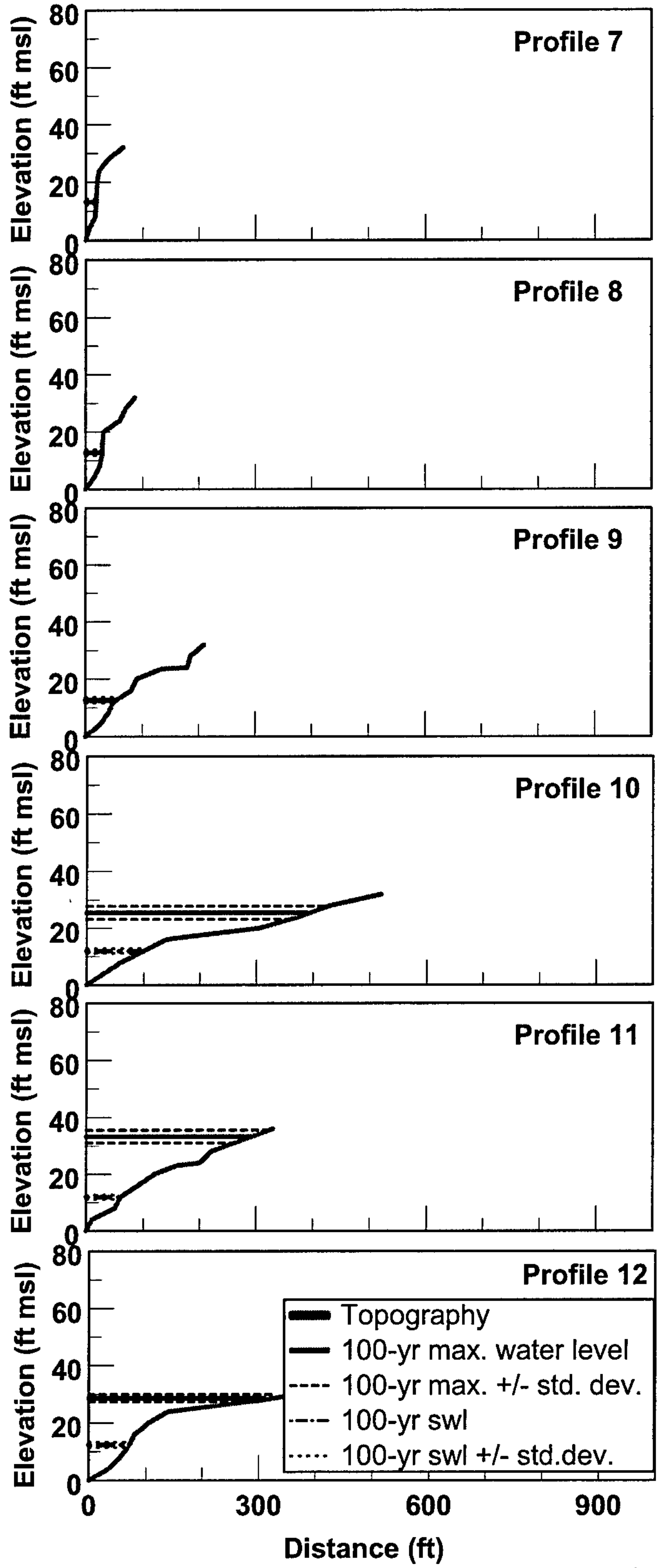
Return Period	Maximum Water Level		Maximum Still Water Level	
yr	Level, ft	Std. Dev., ft	Level, ft	Std. Dev., ft
2	16.1	3.9	4.3	1.3
5	28.4	2.6	9.4	0.9
10	34.1	1.5	11.6	0.6
25	36.7	1.1	12.5	0.3
50	38.1	1.2	12.9	0.4
75	39.1	1.4	13.2	0.4
100	39.5	1.6	13.4	0.5
500	41.3	2.0	14.0	0.6

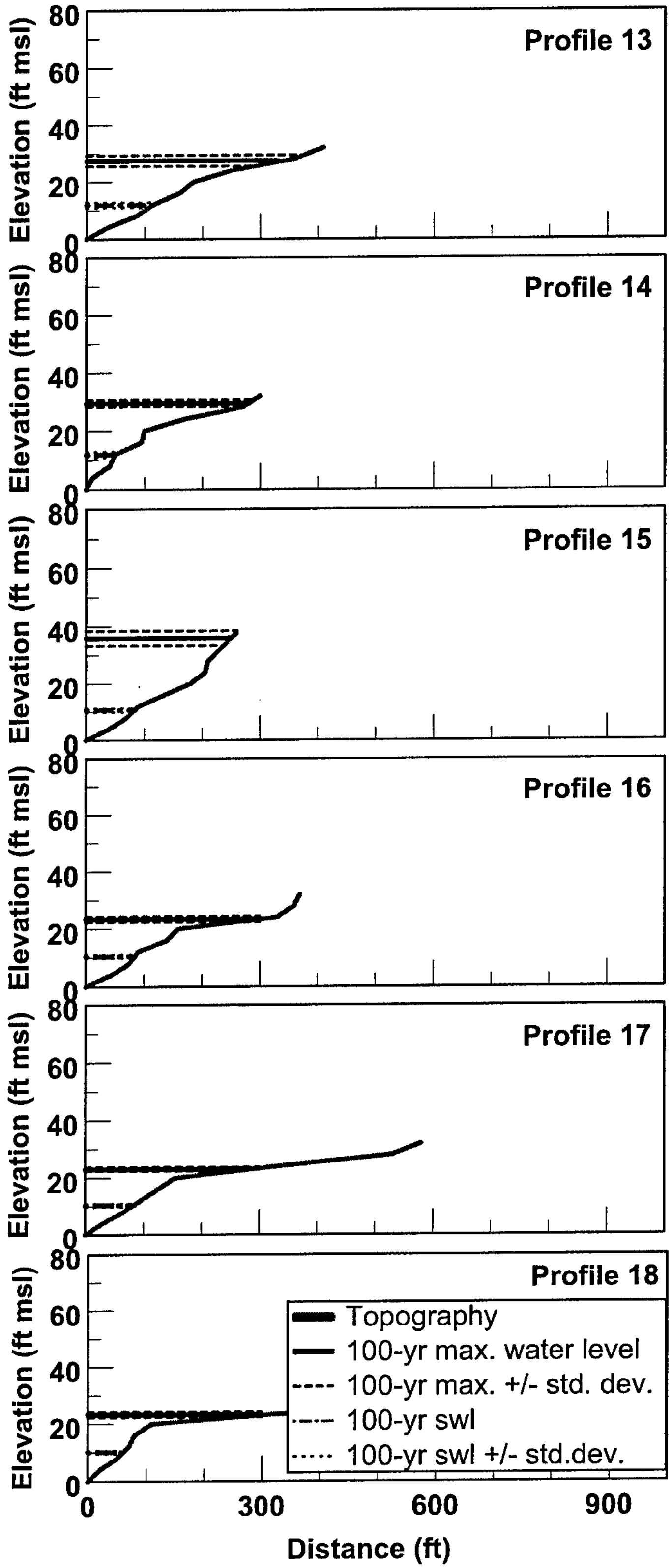
Appendix E Stage-Frequency Relationship Plots

This appendix contains stage-frequency relationship plots for profiles along the Rota coast. Maximum water level (including storm surge, wave ponding on the reef, and wave runup) with a 100-yr return period and its standard deviation are given for each profile. The plots also include maximum still water level (including storm surge, wave ponding on the reef, and nearshore wave setup) and its standard deviation for each profile and return interval. The reference datum is msl.

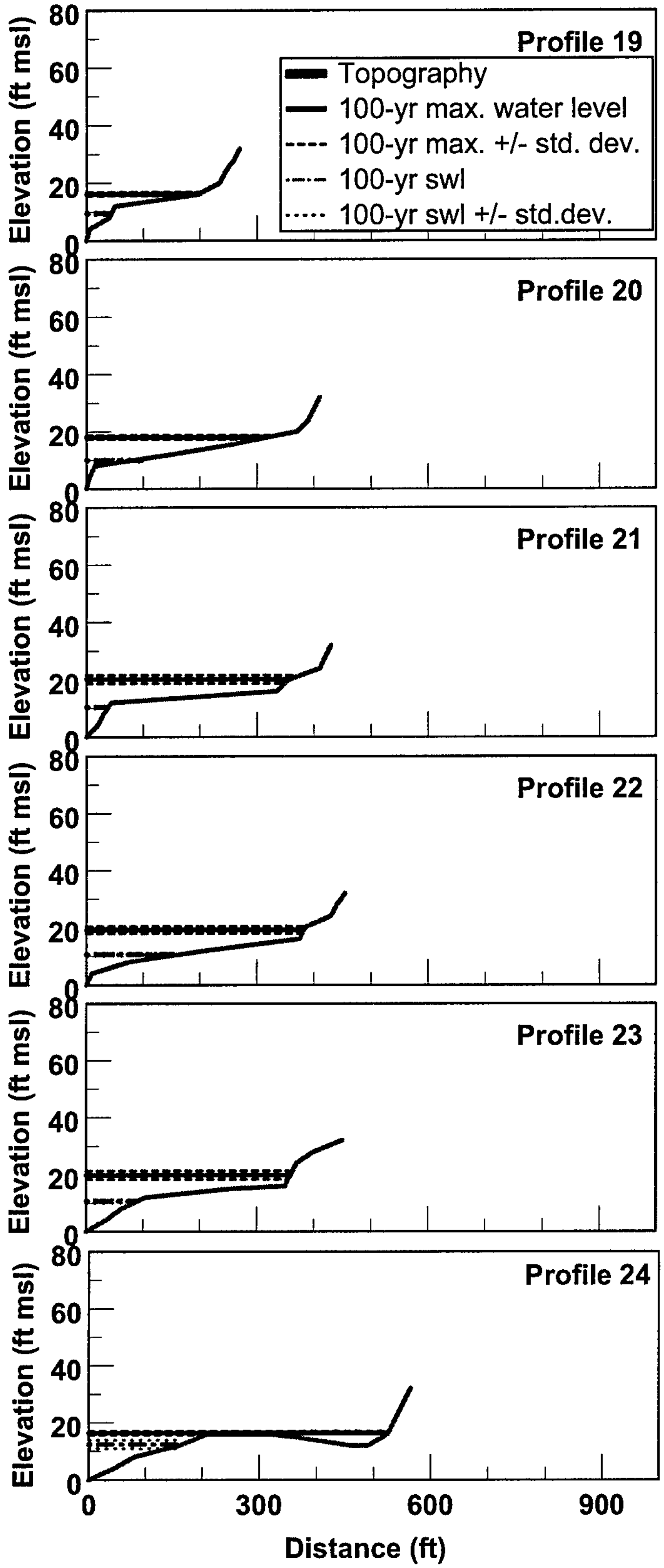
Only the maximum still water level information is shown for Profiles 5 through 9. These profiles required a low bluff methodology for mapping flood limits. Hence, wave runup was computed on an imaginary extension of the actual bluff face and it is not meaningful to display in the plots.

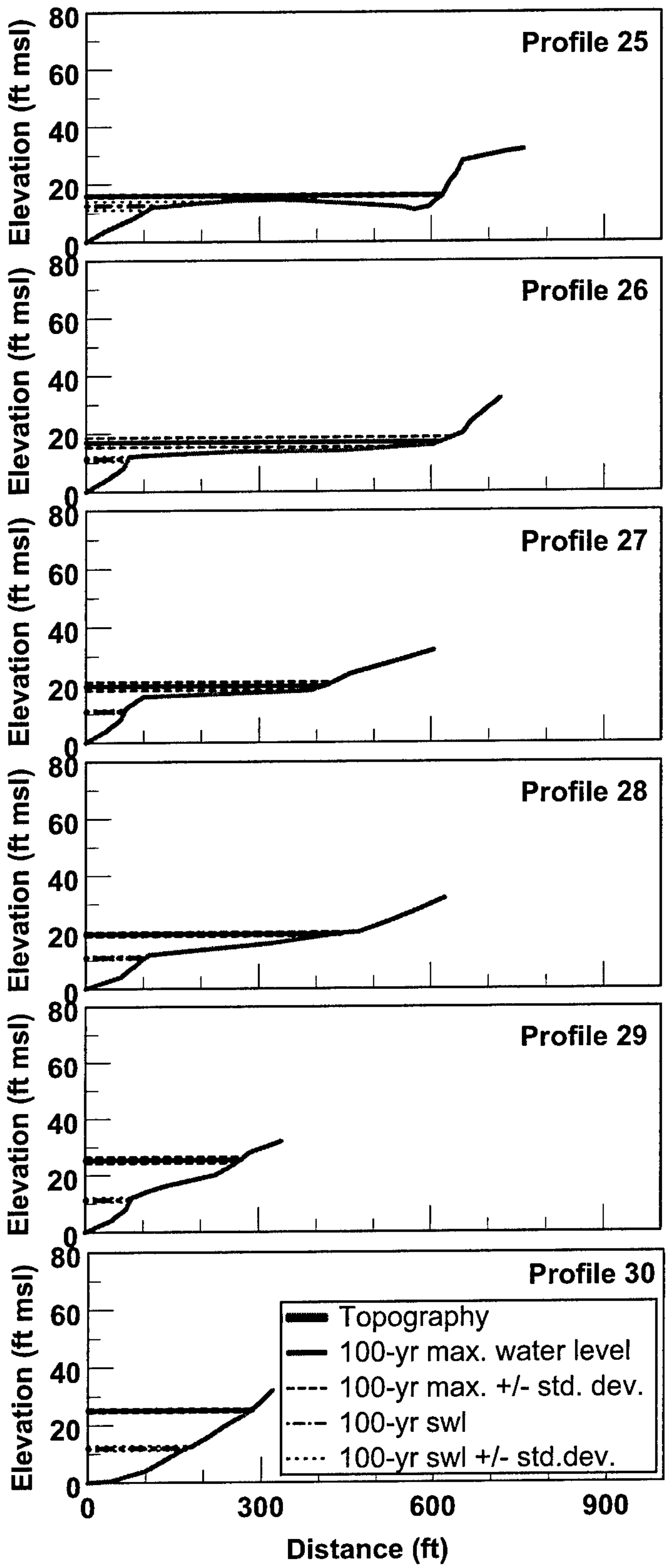

Profile 1
Profile 2
Profile 3
Profile 4
Profile 5
Profile 6
Elevation (ft msl)
0
20
40
60
80
0
300
600
900
Distance (ft)
Topography
100-yr max. water level
100-yr max. +/- std. dev.
100-yr swl
100-yr swl +/- std.dev.

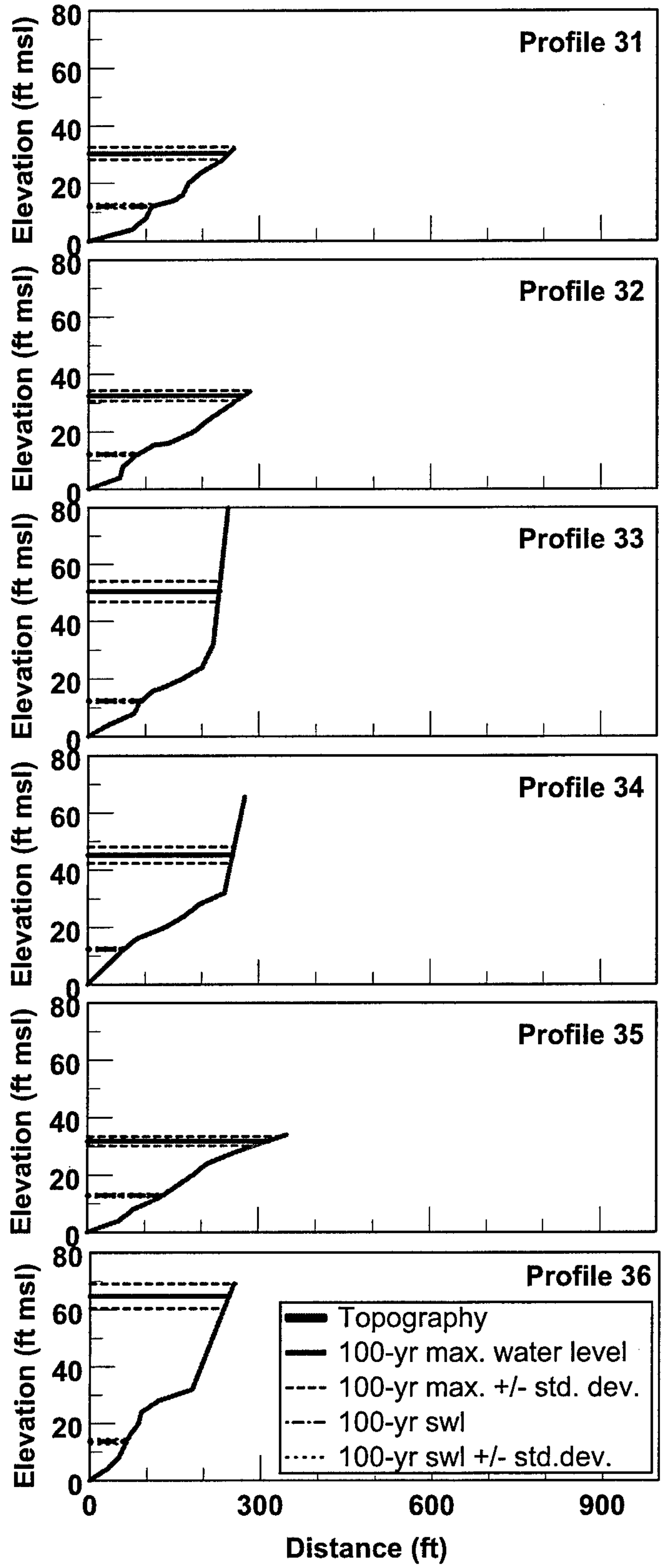

Profile 7
Profile 8
Profile 9
Profile 10
Profile 11
Profile 12
Elevation (ft msl)
0
20
40
60
80
0
300
600
900
Distance (ft)
Topography
100-yr max. water level
100-yr max. +/- std. dev.
100-yr swl
100-yr swl +/- std.dev.



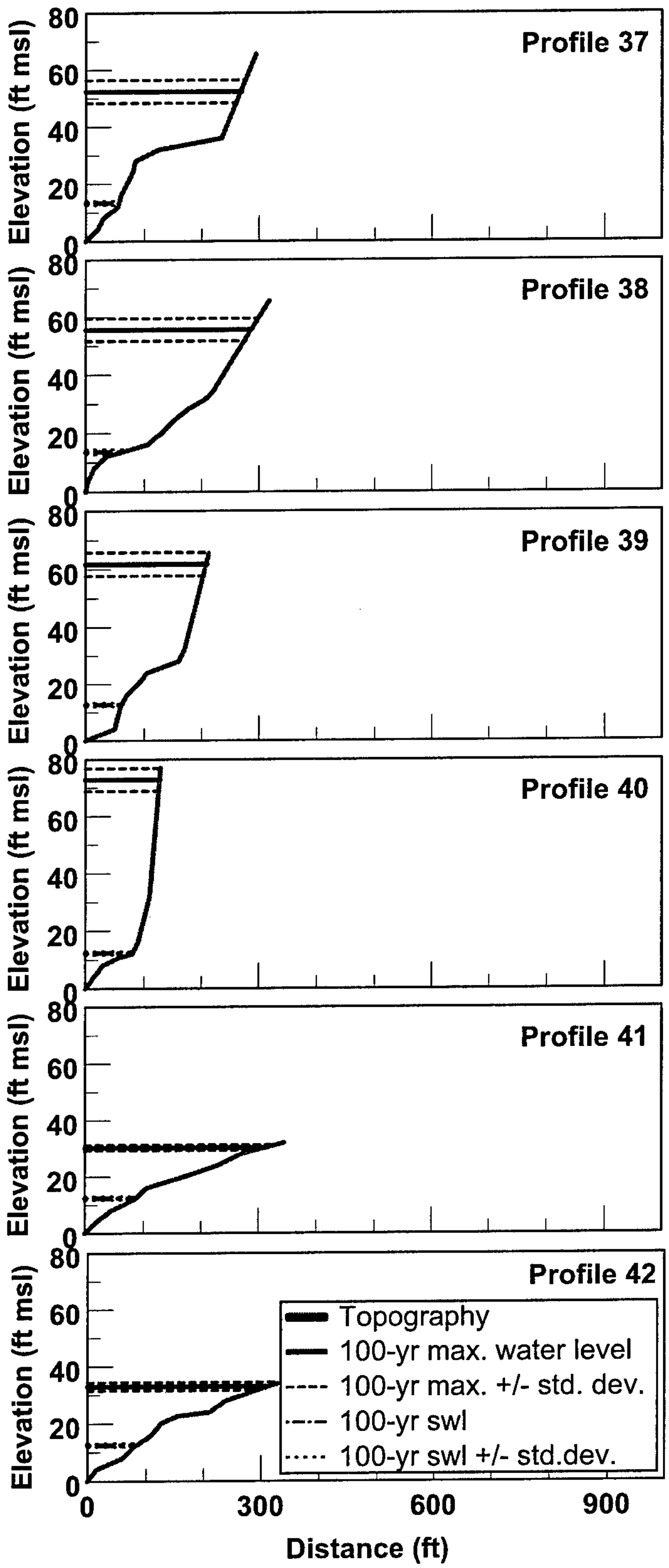
Profile 13
Profile 14
Profile 15
Profile 16
Profile 17
Profile 18
Elevation (ft msl)
0
20
40
60
80
Distance (ft)
0
300
600
900
Topography
100-yr max. water level
100-yr max. +/- std. dev.
100-yr swl
100-yr swl +/- std.dev.

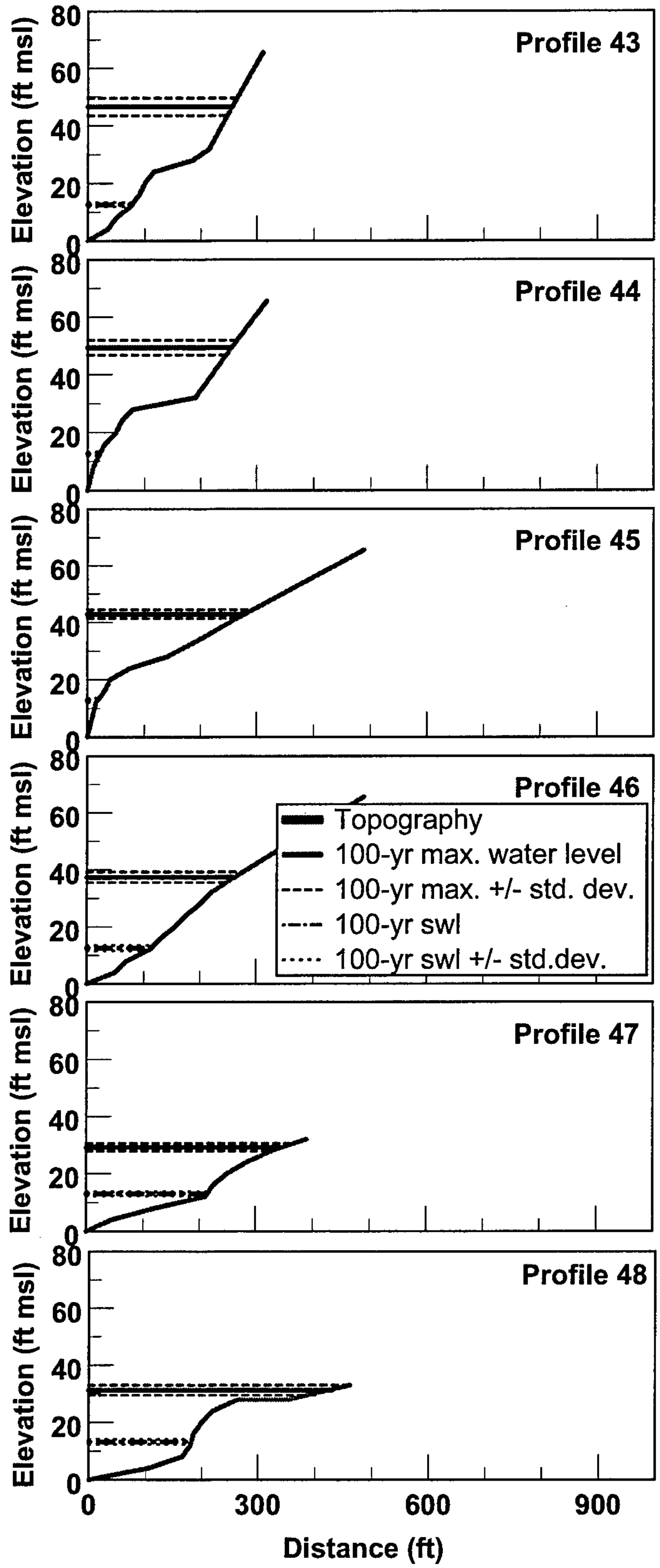

Profile 19
Topography
100-yr max. water level
100-yr max. +/- std. dev.
100-yr swl
100-yr swl +/- std.dev.
Profile 20
Profile 21
Profile 22
Profile 23
Profile 24
Elevation (ft msl)
0
20
40
60
80
0
300
600
900
Distance (ft)

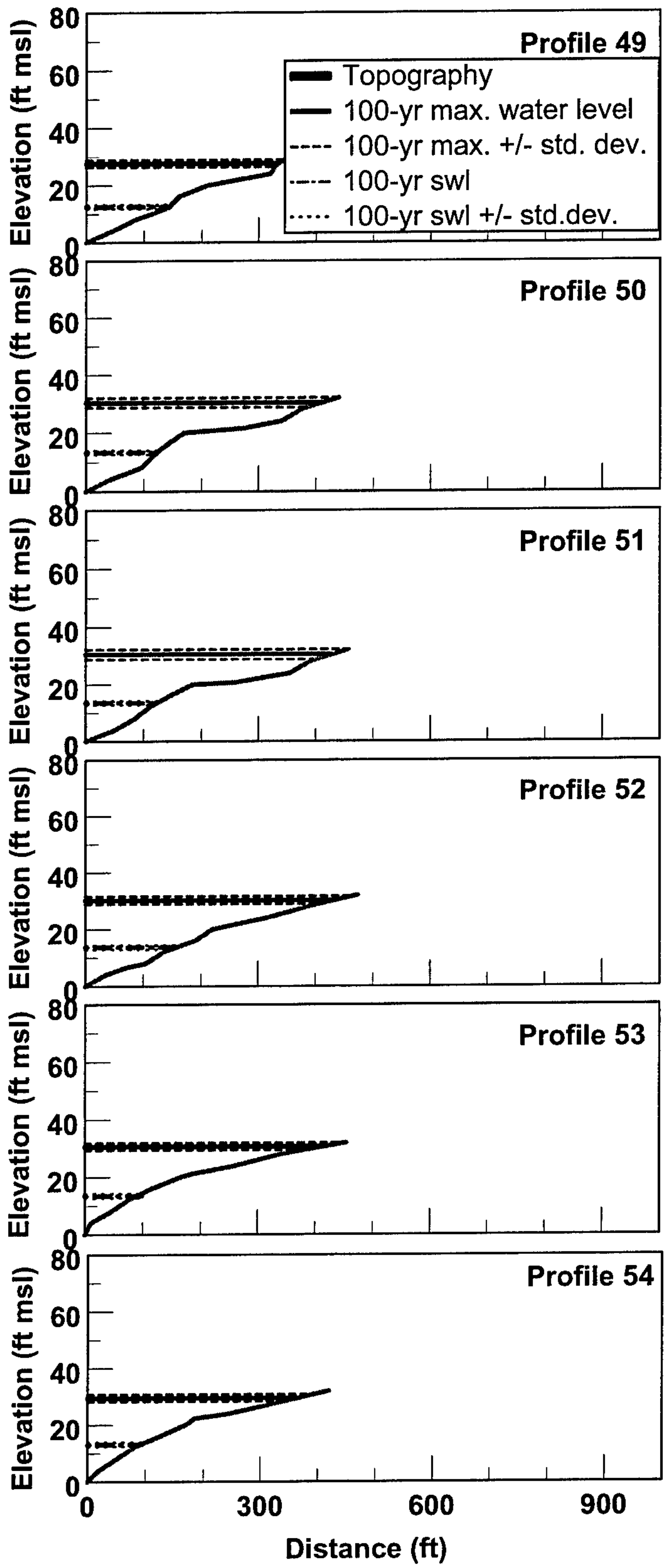

Profile 25
Profile 26
Profile 27
Profile 28
Profile 29
Profile 30
Elevation (ft msl)
0
20
40
60
80
Topography
100-yr max. water level
100-yr max. +/- std. dev.
100-yr swl
100-yr swl +/- std.dev.
0
300
600
900
Distance (ft)



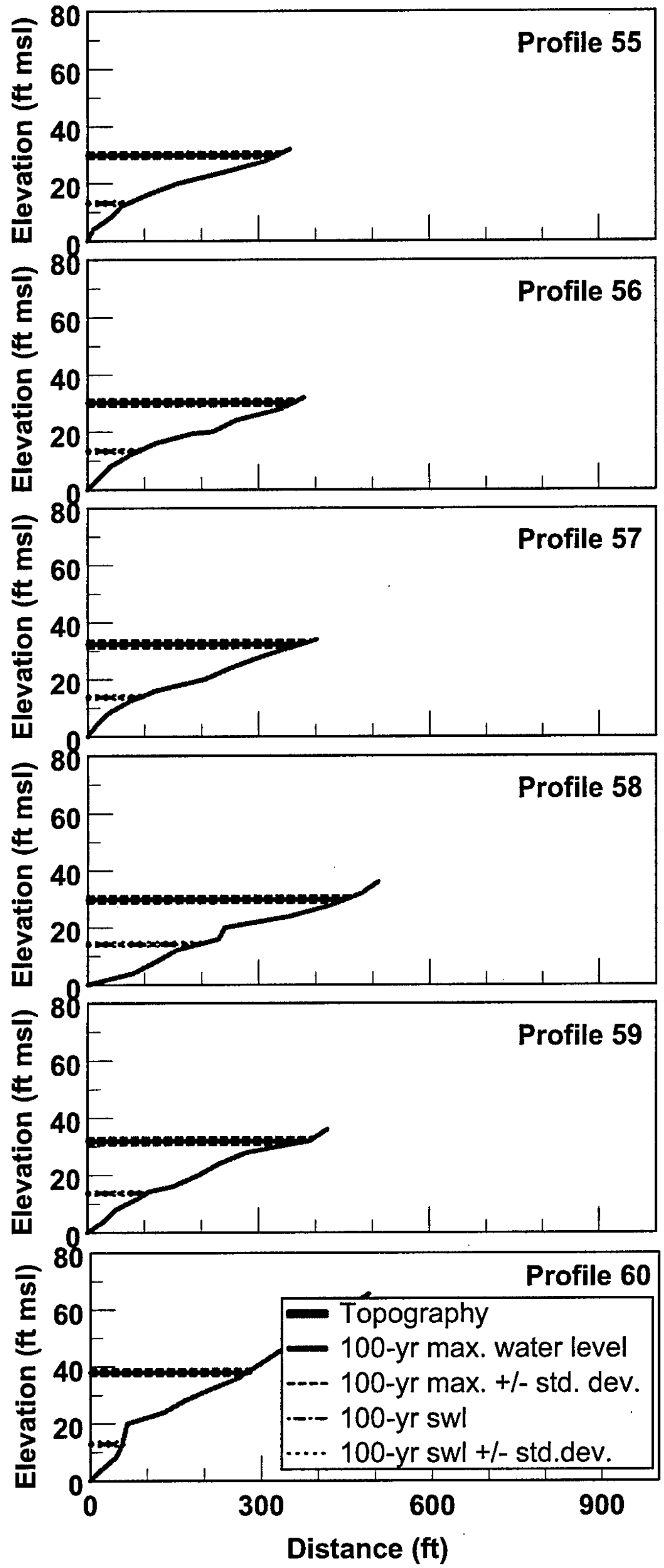
Profile 31
Profile 32
Profile 33
Profile 34
Profile 35
Profile 36
Elevation (ft msl)
0
20
40
60
80
0
300
600
900
Distance (ft)
Topography
100-yr max. water level
100-yr max. +/- std. dev.
100-yr swl
100-yr swl +/- std.dev.

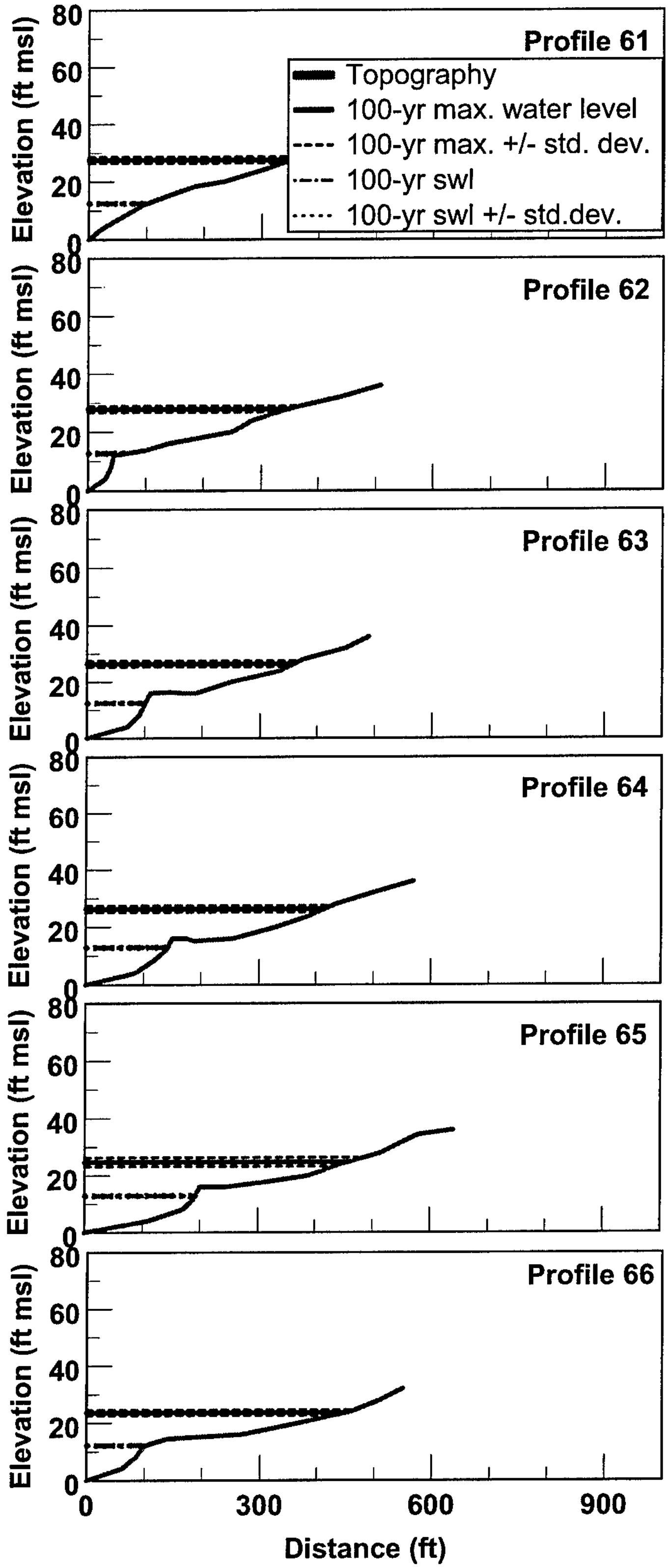

Profile 37
Profile 38
Profile 39
Profile 40
Profile 41
Profile 42
Elevation (ft msl)
Distance (ft)
0
20
40
60
80
300
600
900
Topography
100-yr max. water level
100-yr max. +/- std. dev.
100-yr swl
100-yr swl +/- std.dev.

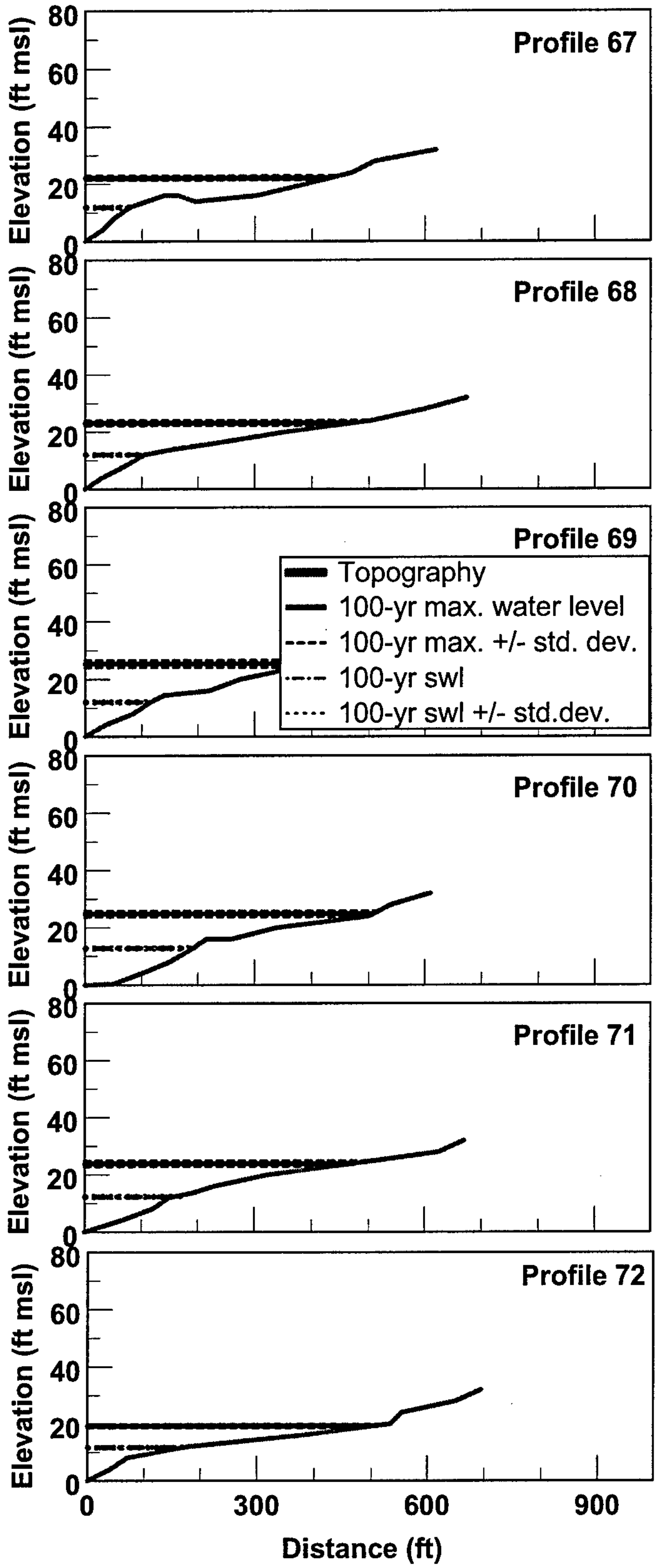

Profile 43
Profile 44
Profile 45
Profile 46
Profile 47
Profile 48
Topography
100-yr max. water level
100-yr max. +/- std. dev.
100-yr swl
100-yr swl +/- std.dev.
Elevation (ft msl)
Distance (ft)
0
20
40
60
80
0
300
600
900

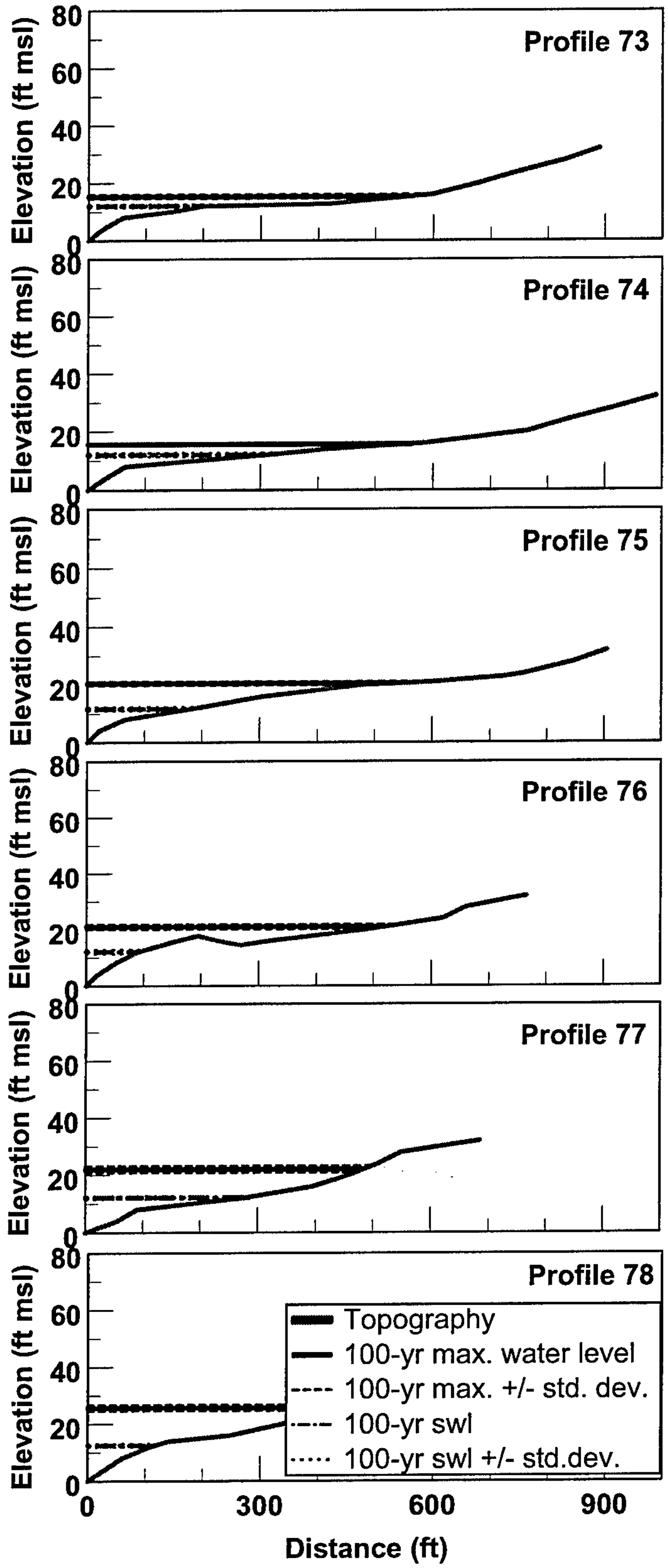


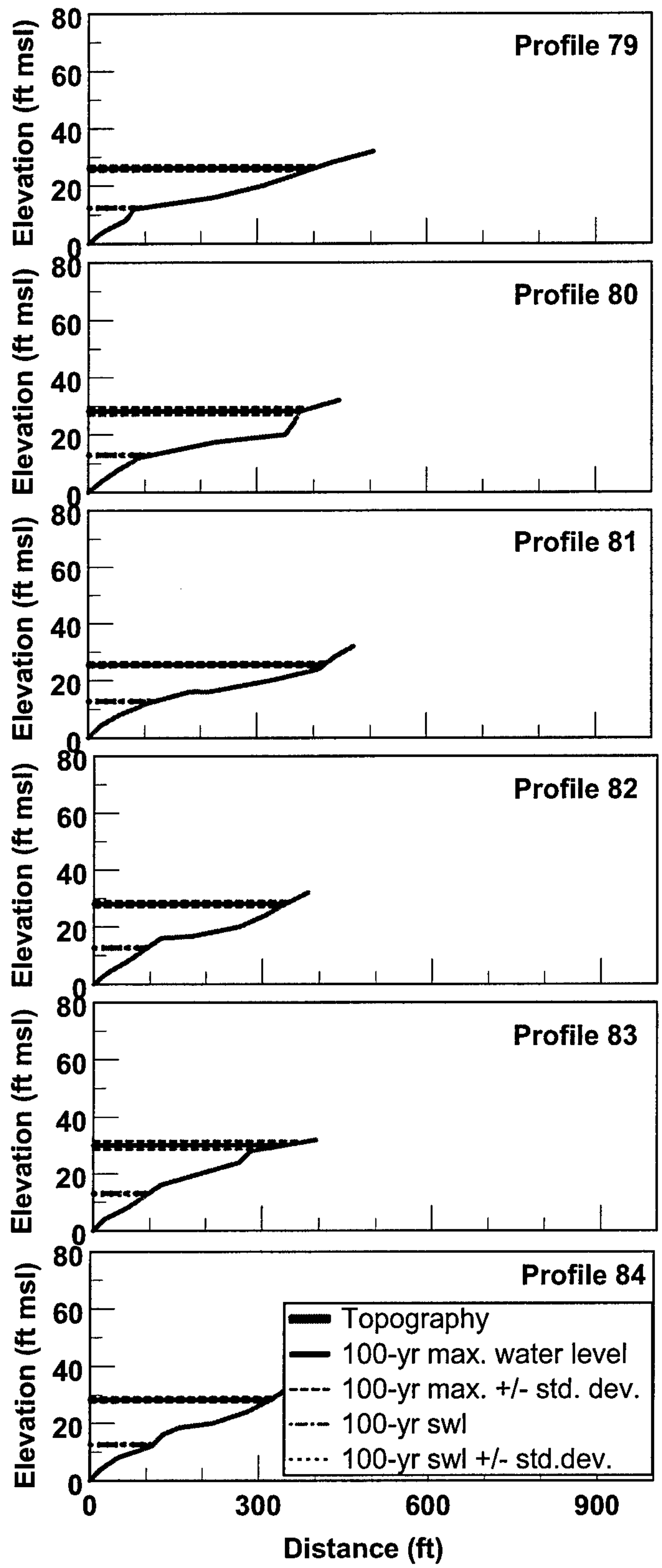
Profile 49
Topography
100-yr max. water level
100-yr max. +/- std. dev.
100-yr swl
100-yr swl +/- std.dev.
Profile 50
Profile 51
Profile 52
Profile 53
Profile 54
Elevation (ft msl)
0
20
40
60
80
0
300
600
900
Distance (ft)

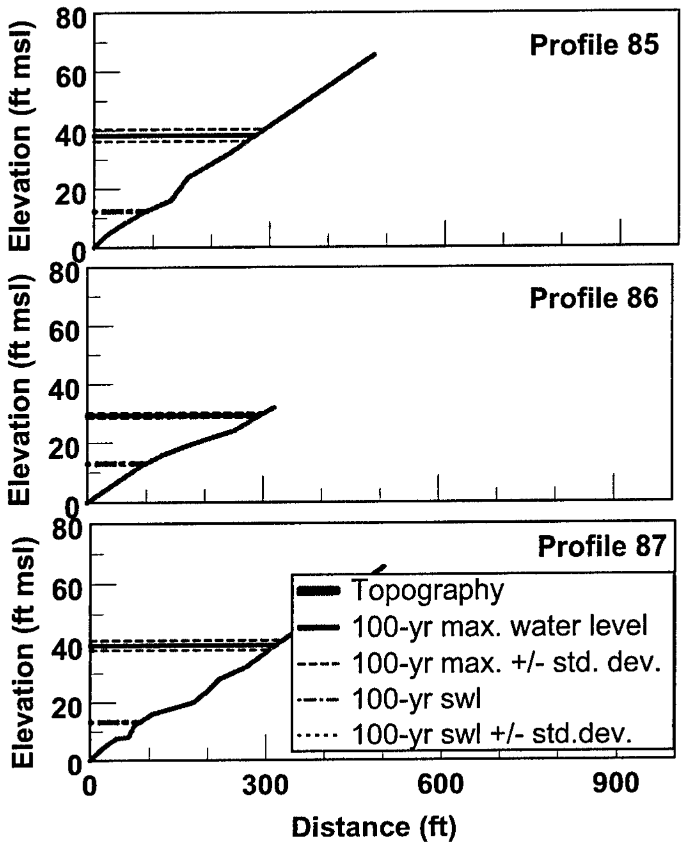

Profile 55
Profile 56
Profile 57
Profile 58
Profile 59
Profile 60
Elevation (ft msl)
80
60
40
20
0
300
600
900
Distance (ft)
Topography
100-yr max. water level
100-yr max. +/- std. dev.
100-yr swl
100-yr swl +/- std.dev.


Profile 61
Topography
100-yr max. water level
100-yr max. +/- std. dev.
100-yr swl
100-yr swl +/- std.dev.
Profile 62
Profile 63
Profile 64
Profile 65
Profile 66
Elevation (ft msl)
0
20
40
60
80
0
300
600
900
Distance (ft)


Profile 67
Profile 68
Profile 69
Profile 70
Profile 71
Profile 72
Topography
100-yr max. water level
100-yr max. +/- std. dev.
100-yr swl
100-yr swl +/- std.dev.
Elevation (ft msl)
Distance (ft)
0
20
40
60
80
0
300
600
900


Profile 73
Profile 74
Profile 75
Profile 76
Profile 77
Profile 78
Elevation (ft msl)
0
20
40
60
80
0
300
600
900
Distance (ft)
Topography
100-yr max. water level
100-yr max. +/- std. dev.
100-yr swl
100-yr swl +/- std.dev.


Profile 79
Profile 80
Profile 81
Profile 82
Profile 83
Profile 84
Elevation (ft msl)
0
20
40
60
80
0
300
600
900
Distance (ft)
Topography
100-yr max. water level
100-yr max. +/- std. dev.
100-yr swl
100-yr swl +/- std.dev.


Profile 85
Profile 86
Profile 87
Elevation (ft msl)
Elevation (ft msl)
Elevation (ft msl)
0
20
40
60
80
0
300
600
900
Distance (ft)
Topography
100-yr max. water level
100-yr max. +/- std. dev.
100-yr swl
100-yr swl +/- std.dev.

Appendix F
Wave Parameter and Water Level Tables by Storm

This appendix contains tables of wave parameters and water level components corresponding to the time of maximum water level for each storm at selected profiles along the Rota coast. Tables were generated for all profiles, but only every fourth table is included here to keep the published report to a manageable size. Profiles 4 and 10 are given in place of Profiles 5 and 9 because the special low bluff methodology applied for Profiles 5 through 9 gives fictitious runups which are subsequently reduced prior to flood mapping. Maximum water level includes storm surge, wave ponding on the reef, and wave runup. Reported wave heights and directions are in 10- to 30-m (33- to 98-ft) depth at the seaward edge of the reef. The reported wave heights and water level components correspond to peak total water level at the profile and may not be the maximum values experienced during the storm.

Explanation of each column in the tables is as follows:

Storm No. = identifying number of the storm,

Hs = significant wave height (average height of the one-third highest waves) in 10- to 30-m (33- to 98-ft) depth at time of maximum total water level,

H1 = average height of the 1 percent highest waves in 10- to 30-m (33- to 98-ft) depth at time of maximum total water level,

Tp = peak spectral wave period in 10- to 30-m (33- to 98-ft) depth at time of maximum total water level,

Dir. = wave direction at time of maximum total water level, in deg azimuth, coming from,

Surge = storm surge at time of maximum total water level,

Ponding = ponding over the reef at time of maximum total water level,

Setup = nearshore wave setup at time of maximum total water level,

Runup = wave runup at shore at time of maximum total water level,

Total = maximum total water during the storm relative to msl datum, including storm surge, ponding, and wave runup.

Table F1

Wave Parameters and Water Levels by Storm, Profile: Rota 1

Storm No.	Hs ft	H1 ft	Tp sec	Dir. deg az	Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
	----Wave Parameters----				-----------Water Levels------------				
2348	9.2	15.3	10	146	0.5	2.4	1.0	16.4	19.2
0150	9.2	15.3	11	126	0.1	2.5	1.1	20.6	23.3
0853	13.1	21.9	14	126	1.2	3.3	1.7	35.6	40.1
1953	13.8	23.0	11	150	0.2	3.4	1.5	21.5	25.1
1557	16.4	27.4	12	131	0.9	3.7	1.9	27.5	32.1
2057	20.4	34.0	14	137	0.3	4.5	2.3	35.4	40.2
1861	13.8	23.0	16	140	0.1	3.8	1.8	42.2	46.1
2762	26.6	44.4	14	135	0.5	5.0	3.0	40.9	46.4
0163	30.2	50.4	14	153	1.4	5.1	3.5	45.4	51.9
2563	11.1	18.6	14	151	0.9	3.1	1.5	34.5	38.5
2965	6.2	10.4	7	167	-0.1	1.3	0.5	8.3	9.5
3367	11.1	18.6	14	160	1.5	2.9	1.5	36.0	40.5
2168	15.4	25.8	11	145	0.4	3.6	1.7	23.0	27.0
0571	14.1	23.6	14	144	0.2	3.7	1.8	34.2	38.2
0676	33.8	56.4	14	142	1.2	5.4	3.8	47.8	54.4
1977	14.1	23.6	11	142	0.1	3.5	1.5	21.6	25.2
2379	12.8	21.4	11	132	0.2	3.3	1.4	20.4	23.8
2187	4.3	7.1	12	160	0.3	0.9	0.5	13.6	14.9
0188	22.6	37.8	12	149	0.4	4.5	2.5	32.2	37.2
0289	13.8	23.0	14	130	0.4	3.6	1.7	34.6	38.6
0190	9.8	16.4	12	126	0.7	2.7	1.2	25.8	29.1
3190	20.4	34.0	14	142	0.7	4.4	2.3	36.0	41.1
2691	4.9	8.2	10	164	0.1	1.1	0.5	12.4	13.6
1592	24.3	40.5	14	139	0.6	4.8	2.8	39.0	44.4
3192	11.1	18.6	14	125	0.8	3.1	1.5	34.5	38.4
3594	0.0	0.0	0	215	0.0	0.0	0.0	0.0	0.0
0597	29.5	49.3	14	141	0.6	5.2	3.3	43.8	49.6
2997	12.2	20.3	14	152	1.1	3.2	1.6	35.4	39.7
1367	11.8	19.7	14	158	1.0	3.2	1.6	35.1	39.3
4367	13.8	23.0	14	154	1.7	3.3	1.8	36.0	41.0
5163	36.4	60.8	16	145	2.1	5.5	4.3	57.7	65.3
6163	23.3	38.9	12	150	0.9	4.5	2.5	33.3	38.7

Table F4
Wave Parameters and Water Levels by Storm, Profile: Rota 4

Storm No.	----Wave Parameters---- Hs ft	H1 ft	Tp sec	Dir. deg az	-----------Water Levels------------ Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
2348	9.5	15.9	10	149	0.5	2.5	1.0	18.2	21.1
0150	10.5	17.5	11	132	0.1	2.8	1.1	19.8	22.8
0853	11.8	19.7	14	130	1.2	3.1	1.5	28.6	32.9
1953	13.8	23.0	11	154	0.3	3.4	1.4	19.5	23.1
1557	15.7	26.3	12	135	0.9	3.6	1.7	22.5	27.1
2057	13.8	23.0	14	133	0.6	3.6	1.7	28.7	32.9
1861	13.5	22.5	16	144	0.1	3.8	1.7	31.9	35.8
2762	25.9	43.3	14	139	0.5	5.0	2.8	29.7	35.1
0163	31.2	52.1	14	156	1.6	5.1	3.4	31.6	38.3
2563	12.5	20.8	14	156	0.9	3.3	1.5	28.7	32.9
2965	4.0	6.6	10	173	0.1	0.6	0.3	10.2	10.9
3367	12.5	20.8	14	164	1.6	3.2	1.6	28.8	33.5
2168	15.4	25.8	11	148	0.5	3.6	1.6	19.8	23.9
0571	14.1	23.6	14	149	0.2	3.7	1.7	28.7	32.6
0676	33.5	55.9	14	145	1.3	5.3	3.6	32.3	39.0
1977	14.1	23.6	11	145	0.1	3.5	1.4	19.5	23.1
2379	10.2	17.0	11	132	0.3	2.7	1.1	19.9	22.9
2187	4.9	8.2	12	164	0.4	1.2	0.5	18.4	20.0
0188	23.0	38.4	12	151	0.5	4.5	2.4	26.2	31.3
0289	14.8	24.7	14	136	0.5	3.8	1.8	28.6	32.8
0190	9.5	15.9	12	130	0.6	2.6	1.1	22.0	25.2
3190	14.1	23.6	14	137	0.6	3.6	1.7	28.7	32.9
2691	5.6	9.3	10	167	0.0	1.4	0.5	16.3	17.7
1592	24.0	40.0	14	142	0.7	4.8	2.6	29.2	34.6
3192	9.8	16.4	14	129	0.9	2.8	1.2	27.0	30.6
3594	1.0	1.6	8	186	0.0	0.0	0.2	6.2	6.1
0597	29.2	48.8	14	144	0.6	5.2	3.1	30.9	36.7
2997	13.5	22.5	14	157	1.1	3.4	1.7	28.8	33.3
1367	12.8	21.4	14	162	1.0	3.3	1.6	28.7	33.1
4367	14.8	24.7	14	158	1.8	3.5	1.9	28.4	33.7
5163	36.8	61.4	16	148	2.1	5.5	4.2	36.3	43.9
6163	24.3	40.5	12	153	0.9	4.6	2.5	27.0	32.5

Table F10
Wave Parameters and Water Levels by Storm, Profile: Rota 10

Storm No.	Hs ft	H1 ft	Tp sec	Dir. deg az	Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
	----Wave Parameters----				-----------Water Levels------------				
2348	9.2	15.3	11	190	0.4	2.5	0.7	8.7	11.6
0150	10.2	17.0	11	158	0.1	2.8	0.8	9.1	12.0
0853	17.4	29.0	12	163	0.3	4.0	1.4	11.8	16.1
1953	15.4	25.8	11	174	0.3	3.6	1.2	10.3	14.3
1557	11.8	19.7	12	156	0.9	3.0	1.0	11.1	15.1
2057	17.7	29.6	14	161	0.3	4.2	1.5	12.4	17.0
1861	14.4	24.1	16	169	0.1	3.9	1.2	12.8	16.8
2762	21.7	36.2	14	157	0.7	4.5	1.9	12.4	17.6
0163	36.8	61.4	14	174	2.0	5.4	3.2	14.0	21.3
2563	18.0	30.1	14	187	1.5	4.0	1.7	12.2	17.7
2965	6.2	10.4	10	194	0.1	1.6	0.4	6.3	8.1
3367	20.7	34.5	14	191	1.9	4.2	1.9	12.1	18.1
2168	14.4	24.1	11	187	0.5	3.4	1.1	10.4	14.4
0571	13.8	23.0	14	167	0.2	3.7	1.1	12.6	16.4
0676	33.5	55.9	14	168	1.4	5.3	2.8	13.1	19.7
1977	13.8	23.0	11	163	0.1	3.4	1.0	10.4	13.9
2379	11.1	18.6	11	160	0.1	3.0	0.9	9.6	12.7
2187	8.9	14.8	12	189	0.5	2.5	0.7	9.2	12.2
0188	24.6	41.1	12	168	0.5	4.7	1.9	11.4	16.6
0289	15.1	25.2	14	163	0.3	3.8	1.3	12.5	16.7
0190	6.6	11.0	12	154	0.4	1.9	0.5	7.6	9.8
3190	17.4	29.0	14	162	0.7	4.1	1.5	12.3	17.1
2691	7.8	13.1	10	189	0.0	2.2	0.5	7.2	9.3
1592	22.6	37.8	14	161	0.7	4.6	2.0	12.3	17.7
3192	16.7	27.9	12	160	0.2	3.9	1.3	11.9	16.1
3594	1.3	2.2	8	206	0.0	0.0	0.2	3.4	3.4
0597	27.5	46.0	14	160	0.7	5.0	2.3	12.6	18.4
2997	18.0	30.1	14	193	2.0	3.8	1.8	12.1	18.0
1367	19.0	31.8	14	185	1.4	4.1	1.8	12.3	17.8
4367	20.4	34.0	14	182	2.0	4.1	1.9	12.1	18.2
5163	37.7	63.0	16	163	2.2	5.5	3.4	16.3	24.0
6163	25.3	42.2	14	190	1.2	4.7	2.2	12.3	18.3

Table F13
Wave Parameters and Water Levels by Storm, Profile: Rota 13

	----Wave Parameters----				-----------Water Levels------------				
Storm No.	Hs ft	H1 ft	Tp sec	Dir. deg az	Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
2348	10.8	18.1	11	188	0.2	2.9	0.9	8.0	11.1
0150	8.9	14.8	11	156	0.1	2.5	0.7	6.5	9.1
0853	17.4	29.0	12	166	0.3	4.0	1.4	10.0	14.2
1953	15.4	25.8	11	184	0.2	3.7	1.2	8.6	12.5
1557	10.5	17.5	12	165	0.8	2.8	0.9	9.1	12.6
2057	16.4	27.4	14	170	0.2	4.1	1.5	13.3	17.5
1861	13.8	23.0	16	179	0.0	3.8	1.2	13.1	17.0
2762	19.7	32.9	14	164	0.5	4.4	1.8	14.7	19.6
0163	37.1	61.9	14	186	1.8	5.4	3.3	16.7	23.9
2563	25.3	42.2	14	204	0.9	4.8	2.2	14.5	20.2
2965	7.8	13.1	10	205	0.1	2.1	0.6	5.4	7.6
3367	26.9	44.9	14	201	1.4	4.8	2.4	14.7	20.9
2168	17.1	28.5	11	176	0.6	3.8	1.4	8.8	13.1
0571	13.1	21.9	14	176	0.1	3.6	1.1	11.2	14.9
0676	31.5	52.6	14	176	1.1	5.2	2.7	15.2	21.5
1977	13.5	22.5	11	171	0.1	3.4	1.1	8.8	12.2
2379	10.2	17.0	11	168	0.1	2.8	0.8	7.4	10.3
2187	12.5	20.8	12	202	0.5	3.2	1.1	9.6	13.3
0188	23.6	39.4	12	176	0.4	4.6	1.9	10.7	15.7
0289	14.1	23.6	14	175	0.3	3.7	1.3	11.7	15.7
0190	8.2	13.7	11	206	0.3	2.3	0.6	6.2	8.8
3190	16.7	27.9	14	172	0.6	4.0	1.5	14.0	18.6
2691	9.2	15.3	10	199	0.0	2.5	0.7	5.9	8.4
1592	18.7	31.2	14	165	0.6	4.2	1.7	14.8	19.6
3192	15.7	26.3	12	168	0.1	3.8	1.3	10.1	14.0
3594	1.0	1.6	9	218	0.0	0.0	0.2	3.3	3.3
0597	26.9	44.9	14	171	0.5	5.1	2.3	14.7	20.2
2997	27.2	45.5	14	201	1.4	4.9	2.4	14.7	21.0
1367	24.3	40.5	14	198	1.2	4.7	2.2	14.4	20.2
4367	22.0	36.7	14	191	1.8	4.3	2.1	14.1	20.2
5163	36.8	61.4	16	173	1.8	5.6	3.4	18.3	25.7
6163	26.9	44.9	14	199	1.0	4.9	2.3	14.7	20.7

Table F17
Wave Parameters and Water Levels by Storm, Profile: Rota 17

Storm No.	Hs ft	H1 ft	Tp sec	Dir. deg az	Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
	----Wave Parameters----				-----------Water Levels------------				
2348	16.4	27.4	10	339	0.9	3.5	0.7	7.9	12.3
0150	4.0	6.6	14	285	0.0	1.0	0.3	6.6	7.6
0853	14.1	23.6	16	295	0.1	3.9	0.6	11.8	15.7
1953	9.2	15.3	14	295	0.0	2.8	0.4	8.9	11.8
1557	11.5	19.2	11	294	0.1	3.0	0.5	7.0	10.1
2057	16.4	27.4	14	340	0.4	4.0	0.7	10.2	14.7
1861	8.5	14.2	12	339	0.1	2.5	0.4	7.2	9.8
2762	23.0	38.4	14	342	1.1	4.6	0.9	12.8	18.5
0163	28.9	48.2	14	297	0.6	5.2	1.0	14.1	19.9
2563	39.3	65.7	16	303	1.1	5.8	1.6	14.5	21.5
2965	11.1	18.6	14	321	0.0	3.3	0.5	9.4	12.6
3367	29.9	49.9	16	340	2.3	5.0	1.4	14.0	21.3
2168	11.8	19.7	11	296	0.1	3.1	0.5	7.0	10.2
0571	7.5	12.6	16	292	0.3	2.5	0.4	10.1	12.9
0676	16.0	26.8	16	300	0.2	4.2	0.6	12.4	16.7
1977	12.8	21.4	12	344	0.5	3.3	0.6	8.1	11.9
2379	6.6	11.0	10	349	0.2	1.7	0.4	5.3	7.2
2187	22.0	36.7	14	313	0.3	4.7	0.8	11.4	16.4
0188	24.6	41.1	16	342	1.6	4.7	1.1	14.1	20.4
0289	17.1	28.5	12	333	0.4	3.9	0.6	9.0	13.3
0190	23.0	38.4	14	333	0.5	4.7	0.8	11.9	17.1
3190	15.4	25.8	12	342	0.3	3.7	0.6	8.5	12.5
2691	19.3	32.3	14	328	-0.1	4.5	0.7	10.3	14.7
1592	15.4	25.8	14	340	0.6	3.8	0.6	10.2	14.7
3192	18.0	30.1	14	339	0.8	4.1	0.7	10.9	15.8
3594	9.8	16.4	11	332	0.0	2.7	0.4	6.5	9.2
0597	26.2	43.8	14	345	1.0	4.9	1.0	13.8	19.8
2997	39.3	65.7	14	330	2.0	5.5	1.7	13.7	21.2
1367	35.7	59.7	16	341	2.2	5.4	1.6	14.3	21.9
4367	29.9	49.9	16	343	2.0	5.1	1.3	14.1	21.1
5163	33.8	56.4	16	337	0.8	5.6	1.3	14.5	20.9
6163	25.6	42.7	14	291	0.5	4.9	0.9	12.8	18.2

Table F21
Wave Parameters and Water Levels by Storm, Profile: Rota 21

Storm No.	----Wave Parameters---- Hs ft	H1 ft	Tp sec	Dir. deg az	----------Water Levels---------- Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
2348	16.7	27.9	10	341	1.0	3.5	0.7	8.2	12.8
0150	4.9	8.2	11	351	0.0	1.2	0.3	10.2	11.4
0853	13.8	23.0	16	299	0.0	3.8	0.6	9.3	13.2
1953	8.9	14.8	14	298	0.0	2.8	0.4	9.9	12.7
1557	10.8	18.1	11	294	0.2	2.9	0.5	9.4	12.4
2057	17.7	29.6	14	344	0.4	4.2	0.7	8.6	13.1
1861	9.5	15.9	12	343	0.0	2.7	0.4	9.7	12.4
2762	24.3	40.5	14	345	1.2	4.7	0.9	8.2	14.0
0163	28.6	47.7	14	299	0.8	5.1	1.0	8.4	14.3
2563	40.0	66.8	14	325	2.0	5.5	1.6	9.0	16.5
2965	10.8	18.1	14	324	0.0	3.2	0.5	9.6	12.8
3367	31.8	53.1	16	343	2.4	5.1	1.4	9.4	16.9
2168	11.5	19.2	11	298	0.1	3.0	0.5	9.3	12.4
0571	7.2	12.1	16	296	0.3	2.4	0.4	10.1	12.8
0676	15.4	25.8	16	303	0.1	4.1	0.6	9.0	13.2
1977	13.8	23.0	12	347	0.3	3.5	0.6	8.9	12.7
2379	7.2	12.1	10	353	0.1	1.9	0.4	10.1	12.1
2187	22.6	37.8	14	320	0.3	4.7	0.8	8.3	13.3
0188	26.6	44.4	16	345	1.6	4.9	1.1	8.6	15.1
0289	17.1	28.5	12	337	0.5	3.9	0.6	8.5	12.9
0190	23.6	39.4	14	336	0.5	4.8	0.8	8.2	13.5
3190	10.8	18.1	14	348	0.3	3.1	0.5	9.4	12.9
2691	19.0	31.8	14	331	-0.1	4.4	0.6	8.7	13.1
1592	16.7	27.9	14	344	0.6	4.0	0.7	8.6	13.1
3192	19.3	32.3	14	343	0.7	4.3	0.7	8.3	13.3
3594	10.2	17.0	11	334	0.0	2.8	0.4	9.6	12.4
0597	27.5	46.0	14	348	1.1	5.0	1.0	8.3	14.4
2997	39.7	66.3	14	309	2.3	5.5	1.6	9.1	16.8
1367	36.8	61.4	16	344	2.4	5.4	1.6	10.7	18.5
4367	31.5	52.6	16	347	2.0	5.2	1.3	8.8	15.9
5163	34.4	57.5	16	340	1.0	5.6	1.3	9.0	15.6
6163	24.9	41.6	14	294	0.6	4.9	0.9	8.2	13.7

Table F25
Wave Parameters and Water Levels by Storm, Profile: Rota 25

Storm No.	----Wave Parameters---- Hs ft	H1 ft	Tp sec	Dir. deg az	-----------Water Levels------------ Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
2348	16.7	27.9	10	341	1.0	3.5	0.6	6.1	10.6
0150	3.6	6.0	14	289	-0.1	0.8	0.3	5.2	6.0
0853	13.8	23.0	16	299	0.0	3.8	0.6	8.9	12.8
1953	8.9	14.8	14	298	0.0	2.8	0.4	6.8	9.5
1557	11.1	18.6	11	297	0.1	3.0	0.5	5.2	8.4
2057	17.7	29.6	14	344	0.4	4.2	0.7	8.0	12.5
1861	9.5	15.9	12	343	0.0	2.7	0.4	5.6	8.4
2762	19.0	31.8	16	345	0.4	4.5	0.7	9.9	14.8
0163	26.6	44.4	14	316	0.5	5.0	0.9	9.1	14.6
2563	19.7	32.9	16	293	0.2	4.6	0.7	9.9	14.7
2965	15.7	26.3	12	325	0.1	3.8	0.6	6.4	10.3
3367	23.3	38.9	14	349	0.9	4.6	0.8	8.9	14.5
2168	11.5	19.2	11	298	0.1	3.0	0.5	5.3	8.4
0571	7.2	12.1	16	296	0.3	2.4	0.4	7.8	10.4
0676	15.4	25.8	16	303	0.2	4.1	0.6	9.3	13.5
1977	13.8	23.0	12	347	0.4	3.5	0.6	6.3	10.1
2379	7.2	12.1	10	353	0.1	1.9	0.4	4.4	6.4
2187	22.6	37.8	14	320	0.4	4.7	0.8	8.7	13.8
0188	25.9	43.3	12	345	0.9	4.7	0.9	7.8	13.4
0289	17.7	29.6	12	336	0.4	4.0	0.6	7.0	11.4
0190	23.6	39.4	14	336	0.5	4.8	0.8	9.0	14.3
3190	10.8	18.1	14	348	0.3	3.1	0.5	7.4	10.8
2691	19.3	32.3	14	333	-0.1	4.5	0.6	8.0	12.4
1592	16.7	27.9	14	344	0.6	4.0	0.7	8.0	12.6
3192	19.3	32.3	14	343	0.7	4.3	0.7	8.4	13.4
3594	10.2	17.0	11	334	0.0	2.8	0.4	5.0	7.8
0597	23.3	38.9	14	353	0.9	4.6	0.8	8.9	14.4
2997	19.7	32.9	16	296	0.2	4.6	0.7	9.9	14.8
1367	19.0	31.8	16	288	0.1	4.5	0.7	9.8	14.4
4367	21.7	36.2	14	352	0.8	4.5	0.8	8.9	14.2
5163	26.9	44.9	14	321	0.3	5.1	0.9	9.0	14.4
6163	19.3	32.3	16	333	0.1	4.6	0.7	9.8	14.5

Table F29
Wave Parameters and Water Levels by Storm, Profile: Rota 29

	----Wave Parameters----				-----------Water Levels------------				
Storm No.	Hs ft	H1 ft	Tp sec	Dir. deg az	Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
2348	16.7	27.9	10	341	0.9	3.6	0.8	8.9	13.4
0150	3.6	6.0	14	289	-0.1	0.8	0.3	4.6	5.4
0853	13.8	23.0	16	299	0.0	3.8	0.7	11.4	15.3
1953	8.9	14.8	14	298	0.0	2.8	0.5	9.6	12.4
1557	11.1	18.6	11	297	0.1	3.0	0.5	7.2	10.3
2057	17.7	29.6	14	344	0.2	4.2	0.8	10.8	15.2
1861	9.5	15.9	12	343	0.0	2.8	0.5	7.2	9.9
2762	24.3	40.5	14	345	0.9	4.7	1.2	11.8	17.4
0163	28.6	47.7	14	299	0.9	5.1	1.5	12.1	18.0
2563	38.7	64.7	16	305	1.3	5.8	2.2	16.1	23.2
2965	15.7	26.3	12	325	0.1	3.8	0.7	9.5	13.4
3367	31.8	53.1	16	343	2.3	5.1	2.0	15.5	22.9
2168	11.5	19.2	11	298	0.1	3.0	0.5	7.3	10.5
0571	7.2	12.1	16	296	0.3	2.4	0.4	10.4	13.0
0676	15.4	25.8	16	303	0.2	4.1	0.7	11.6	15.8
1977	13.8	23.0	12	347	0.3	3.5	0.6	9.2	13.0
2379	7.2	12.1	10	353	0.1	1.9	0.4	4.1	6.1
2187	22.6	37.8	14	320	0.4	4.7	1.1	11.6	16.7
0188	26.6	44.4	16	345	1.4	4.9	1.5	13.3	19.6
0289	17.7	29.6	12	336	0.4	4.0	0.8	10.1	14.5
0190	23.6	39.4	14	336	0.5	4.8	1.1	11.7	17.0
3190	16.4	27.4	12	345	0.2	3.9	0.7	9.7	13.8
2691	19.3	32.3	14	333	-0.1	4.5	0.9	10.9	15.4
1592	16.7	27.9	14	344	0.5	4.0	0.8	10.7	15.1
3192	19.3	32.3	14	343	0.5	4.3	0.9	11.2	16.1
3594	10.2	17.0	11	334	0.0	2.8	0.5	6.2	8.9
0597	27.5	46.0	14	348	0.9	5.0	1.4	11.9	17.8
2997	33.1	55.3	16	328	1.4	5.4	1.9	15.1	22.0
1367	36.8	61.4	16	344	2.3	5.4	2.2	16.2	24.0
4367	31.5	52.6	16	347	1.7	5.2	1.9	15.0	22.0
5163	34.4	57.5	16	340	1.0	5.6	1.9	15.2	21.8
6163	24.9	41.6	14	294	0.7	4.8	1.2	11.8	17.4

Table F33
Wave Parameters and Water Levels by Storm, Profile: Rota 33

	----Wave Parameters----				-----------Water Levels------------				
Storm No.	Hs ft	H1 ft	Tp sec	Dir. deg az	Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
2348	13.1	21.9	11	347	0.9	3.2	1.2	12.1	16.1
0150	5.6	9.3	11	354	0.0	1.5	0.4	5.0	6.4
0853	15.7	26.3	14	350	0.7	3.8	1.5	16.7	21.2
1953	11.1	18.6	11	348	0.5	2.9	1.0	11.8	15.2
1557	10.5	17.5	11	300	0.1	2.8	0.9	11.1	14.0
2057	19.0	31.8	14	348	0.3	4.3	1.8	17.0	21.7
1861	10.2	17.0	12	347	0.0	2.9	0.9	11.8	14.7
2762	22.0	36.7	16	348	0.6	4.7	2.2	26.4	31.8
0163	27.9	46.6	14	301	0.7	5.1	2.5	17.5	23.3
2563	39.3	65.7	16	330	1.6	5.7	3.7	36.1	43.4
2965	15.7	26.3	12	327	0.0	3.8	1.3	13.5	17.4
3367	33.5	55.9	16	346	2.3	5.2	3.3	31.3	38.8
2168	11.1	18.6	11	301	0.1	3.0	0.9	11.5	14.5
0571	10.5	17.5	12	348	0.1	3.0	0.9	12.2	15.2
0676	14.8	24.7	16	306	0.2	4.0	1.4	18.2	22.3
1977	14.8	24.7	12	351	0.4	3.6	1.3	13.5	17.5
2379	7.8	13.1	10	356	0.1	2.1	0.6	6.1	8.3
2187	20.0	33.4	14	314	0.2	4.5	1.8	16.9	21.6
0188	22.3	37.3	16	351	1.3	4.6	2.3	27.4	33.2
0289	15.4	25.8	12	346	0.4	3.7	1.4	13.4	17.6
0190	18.4	30.7	14	348	0.7	4.2	1.8	17.1	22.0
3190	11.8	19.7	14	352	0.3	3.3	1.1	14.4	18.0
2691	19.0	31.8	14	330	-0.1	4.4	1.7	17.0	21.4
1592	17.7	29.6	14	348	0.5	4.1	1.7	17.1	21.8
3192	19.3	32.3	14	346	0.6	4.3	1.8	17.0	21.9
3594	10.5	17.5	11	337	0.0	2.9	0.9	10.9	13.7
0597	28.9	48.2	14	351	0.9	5.1	2.6	17.9	23.9
2997	40.4	67.4	14	334	2.0	5.6	3.7	28.4	36.0
1367	38.1	63.6	16	347	2.2	5.5	3.7	36.0	43.7
4367	33.5	55.9	16	350	1.8	5.3	3.2	30.1	37.2
5163	34.8	58.1	16	342	0.9	5.6	3.2	29.5	36.0
6163	18.7	31.2	16	336	0.1	4.5	1.8	23.5	28.1

Table F37
Wave Parameters and Water Levels by Storm, Profile: Rota 37

	----Wave Parameters----				-----------Water Levels-----------				
Storm No.	Hs ft	H1 ft	Tp sec	Dir. deg az	Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
2348	16.9	28.3	10	343	0.9	3.6	1.7	22.2	26.7
0150	5.4	9.0	11	355	0.0	1.4	0.5	15.0	16.4
0853	13.3	22.2	16	302	0.1	3.8	1.6	30.2	34.1
1953	8.4	14.0	14	302	0.0	2.6	0.9	26.4	29.1
1557	8.5	14.2	11	354	0.8	2.2	1.0	22.3	25.3
2057	14.3	23.9	14	349	0.3	3.7	1.7	28.7	32.7
1861	9.8	16.4	12	347	0.0	2.8	1.1	25.3	28.1
2762	19.8	33.0	16	348	0.6	4.5	2.4	29.8	34.9
0163	28.6	47.8	14	312	0.5	5.2	3.1	28.6	34.3
2563	39.5	65.9	16	330	1.7	5.7	4.4	38.5	45.9
2965	10.9	18.2	14	326	0.0	3.2	1.3	28.4	31.6
3367	32.8	54.7	16	346	2.3	5.2	3.8	33.7	41.2
2168	8.5	14.2	12	349	0.4	2.4	1.0	24.8	27.6
0571	6.8	11.3	16	300	0.3	2.2	0.8	26.3	28.9
0676	15.0	25.1	16	306	0.2	4.0	1.9	30.4	34.6
1977	14.4	24.0	12	351	0.5	3.5	1.6	24.4	28.4
2379	7.6	12.7	10	356	0.2	2.0	0.8	17.6	19.8
2187	23.1	38.5	14	330	0.4	4.7	2.5	27.9	33.0
0188	27.2	45.5	16	349	1.7	4.9	3.2	29.1	35.8
0289	17.8	29.8	12	338	0.4	4.0	1.9	25.7	30.1
0190	23.8	39.7	14	338	0.4	4.8	2.6	28.2	33.4
3190	11.4	19.0	14	352	0.4	3.2	1.4	28.6	32.2
2691	14.9	24.9	14	320	0.0	3.9	1.7	28.7	32.6
1592	14.3	23.8	14	351	0.6	3.6	1.7	28.5	32.8
3192	20.1	33.6	14	347	0.7	4.4	2.2	27.8	32.9
3594	10.4	17.3	11	337	0.0	2.8	1.1	21.3	24.1
0597	28.3	47.3	14	351	1.1	5.0	3.1	28.4	34.5
2997	32.8	54.7	16	330	1.4	5.4	3.7	32.3	39.0
1367	37.6	62.8	16	347	2.2	5.5	4.3	39.1	46.8
4367	32.8	54.7	16	350	2.0	5.3	3.8	33.1	40.3
5163	34.6	57.7	16	342	0.9	5.6	3.9	33.7	40.2
6163	18.8	31.4	16	336	0.1	4.5	2.3	30.3	34.9

Table F41
Wave Parameters and Water Levels by Storm, Profile: Rota 41

Storm No.	----Wave Parameters---- Hs ft	H1 ft	Tp sec	Dir. deg az	-----------Water Levels------------ Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
2348	11.8	19.7	11	342	0.9	2.9	1.1	13.1	16.9
0150	4.0	6.6	14	285	0.0	1.0	0.3	9.1	10.1
0853	14.1	23.6	16	295	0.1	3.9	1.4	17.4	21.4
1953	9.2	15.3	14	295	0.0	2.8	0.8	13.9	16.8
1557	11.5	19.2	11	294	0.1	3.0	1.0	13.3	16.4
2057	16.4	27.4	14	340	0.4	4.0	1.6	16.6	21.0
1861	8.5	14.2	12	339	0.0	2.5	0.7	12.0	14.5
2762	18.7	31.2	16	341	0.8	4.3	2.0	18.7	23.8
0163	28.9	48.2	14	297	0.7	5.1	2.7	16.7	22.6
2563	39.3	65.7	16	303	1.2	5.8	3.8	21.2	28.3
2965	11.1	18.6	14	321	0.0	3.3	1.0	15.1	18.4
3367	29.9	49.9	16	340	2.3	5.0	3.1	19.3	26.6
2168	11.8	19.7	11	296	0.1	3.1	1.0	13.3	16.5
0571	7.5	12.6	16	292	0.3	2.5	0.7	14.4	17.2
0676	16.0	26.8	16	300	0.2	4.2	1.6	18.2	22.5
1977	12.8	21.4	12	344	0.5	3.3	1.2	14.3	18.0
2379	6.6	11.0	10	349	0.2	1.7	0.5	8.5	10.4
2187	17.4	29.0	14	306	0.1	4.2	1.7	16.6	20.9
0188	21.7	36.2	16	344	1.6	4.5	2.4	18.8	24.9
0289	14.1	23.6	12	339	0.5	3.5	1.3	14.2	18.2
0190	16.4	27.4	14	341	0.7	3.9	1.7	16.5	21.1
3190	14.8	24.7	12	342	0.2	3.7	1.3	14.3	18.1
2691	19.3	32.3	14	324	0.0	4.5	1.8	16.5	20.9
1592	15.4	25.8	14	340	0.7	3.8	1.6	16.5	20.9
3192	18.0	30.1	14	339	0.7	4.1	1.8	16.4	21.2
3594	9.8	16.4	11	331	-0.1	2.7	0.8	12.4	15.1
0597	26.2	43.8	14	345	1.1	4.8	2.5	16.4	22.3
2997	39.3	65.7	14	330	2.0	5.5	3.7	19.7	27.2
1367	35.7	59.7	16	341	2.1	5.4	3.6	20.6	28.1
4367	29.9	49.9	16	343	2.0	5.1	3.0	19.1	26.1
5163	33.8	56.4	16	337	0.9	5.6	3.3	19.8	26.3
6163	19.3	32.3	16	329	0.1	4.6	2.0	18.8	23.5

Table F45
Wave Parameters and Water Levels by Storm, Profile: Rota 45

	----Wave Parameters----				-----------Water Levels------------				
Storm No.	Hs ft	H1 ft	Tp sec	Dir. deg az	Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
2348	11.8	19.7	11	342	0.9	2.9	1.1	21.8	25.6
0150	4.9	8.2	10	349	-0.1	1.1	0.4	14.8	15.9
0853	14.1	23.6	16	295	0.1	3.9	1.4	28.1	32.0
1953	9.2	15.3	14	295	0.0	2.8	0.8	23.1	26.0
1557	11.5	19.2	11	294	0.2	3.0	1.0	22.0	25.1
2057	16.4	27.4	14	340	0.3	4.0	1.6	26.4	30.7
1861	8.5	14.2	12	339	0.0	2.5	0.7	22.1	24.6
2762	18.7	31.2	16	341	0.6	4.4	2.0	30.8	35.8
0163	28.9	48.2	14	297	0.9	5.1	2.7	26.7	32.7
2563	39.3	65.7	16	303	1.5	5.8	3.9	33.1	40.4
2965	11.1	18.6	14	321	0.0	3.3	1.0	24.2	27.4
3367	29.9	49.9	16	340	2.4	5.0	3.1	30.3	37.7
2168	11.8	19.7	11	296	0.1	3.1	1.0	21.9	25.1
0571	7.5	12.6	16	292	0.3	2.5	0.7	23.4	26.2
0676	16.0	26.8	16	300	0.2	4.1	1.6	29.7	34.0
1977	12.8	21.4	12	344	0.3	3.3	1.2	23.0	26.6
2379	7.2	12.1	9	349	0.2	1.8	0.6	19.5	21.5
2187	17.4	29.0	14	306	0.2	4.2	1.7	26.3	30.6
0188	21.7	36.2	16	344	1.4	4.5	2.3	30.7	36.6
0289	14.1	23.6	12	339	0.5	3.5	1.3	22.8	26.8
0190	16.4	27.4	14	341	0.7	3.9	1.7	26.4	31.0
3190	14.8	24.7	12	342	0.2	3.7	1.3	22.8	26.6
2691	19.3	32.3	14	324	0.0	4.5	1.8	26.0	30.4
1592	15.4	25.8	14	340	0.6	3.8	1.6	26.2	30.7
3192	17.1	28.5	14	339	0.7	4.0	1.7	26.3	31.0
3594	9.8	16.4	11	331	0.0	2.7	0.9	21.9	24.6
0597	26.2	43.8	14	345	1.0	4.9	2.5	26.1	32.0
2997	33.8	56.4	16	325	1.6	5.4	3.4	31.3	38.4
1367	35.7	59.7	16	341	2.3	5.4	3.6	32.0	39.7
4367	29.9	49.9	16	343	1.9	5.1	3.0	30.2	37.1
5163	33.8	56.4	16	337	1.1	5.5	3.3	31.2	37.8
6163	19.3	32.3	16	329	0.2	4.6	2.0	30.8	35.5

Table F49
Wave Parameters and Water Levels by Storm, Profile: Rota 49

	----Wave Parameters----				-----------Water Levels------------				
Storm No.	Hs ft	H1 ft	Tp sec	Dir. deg az	Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
2348	13.8	23.0	11	353	0.8	3.3	1.1	7.6	11.7
0150	6.9	11.5	11	3	-0.1	2.0	0.5	4.8	6.7
0853	19.0	31.8	14	3	0.3	4.3	1.7	12.6	17.2
1953	12.2	20.3	11	355	0.3	3.1	1.0	7.3	10.7
1557	10.5	17.5	11	2	0.5	2.8	0.9	6.9	10.1
2057	22.3	37.3	14	359	-0.3	4.8	1.8	12.8	17.4
1861	11.5	19.2	12	354	-0.1	3.2	0.9	7.6	10.6
2762	25.9	43.3	16	359	-0.5	5.3	2.2	16.0	20.9
0163	27.5	46.0	14	316	0.0	5.2	2.2	13.2	18.5
2563	39.0	65.2	16	334	0.8	5.9	3.4	17.2	23.9
2965	15.1	25.2	12	332	0.0	3.8	1.2	8.9	12.6
3367	37.4	62.5	16	355	2.1	5.5	3.4	17.5	25.2
2168	10.5	17.5	12	357	0.2	2.9	0.8	7.3	10.4
0571	12.2	20.3	12	356	-0.1	3.3	0.9	7.9	11.0
0676	13.5	22.5	16	313	0.2	3.8	1.2	11.6	15.6
1977	16.0	26.8	12	357	-0.1	3.9	1.3	9.0	12.9
2379	8.9	14.8	10	3	-0.1	2.4	0.6	5.4	7.8
2187	23.3	38.9	14	338	0.1	4.8	2.0	12.7	17.7
0188	30.8	51.5	16	355	0.8	5.4	2.8	15.8	22.0
0289	18.7	31.2	12	346	0.3	4.1	1.5	9.1	13.5
0190	24.9	41.6	14	344	0.4	4.9	2.1	12.6	18.0
3190	14.1	23.6	14	0	0.0	3.8	1.2	10.6	14.4
2691	18.7	31.2	14	346	0.0	4.4	1.6	12.4	16.8
1592	20.0	33.4	14	355	0.0	4.5	1.7	12.7	17.2
3192	22.3	37.3	14	356	0.2	4.7	1.9	12.8	17.7
3594	10.5	17.5	11	342	-0.1	2.9	0.8	6.7	9.5
0597	31.2	52.1	14	356	0.3	5.4	2.5	14.1	19.9
2997	40.7	67.9	14	338	1.6	5.7	3.5	15.9	23.2
1367	40.0	66.8	16	353	2.2	5.6	3.7	18.0	25.8
4367	36.4	60.8	16	356	1.1	5.7	3.2	16.9	23.7
5163	32.5	54.2	16	351	1.7	5.3	3.0	16.3	23.3
6163	18.7	31.2	16	342	-0.1	4.5	1.7	14.5	19.0

Table F53
Wave Parameters and Water Levels by Storm, Profile: Rota 53

Storm No.	----Wave Parameters---- Hs ft	H1 ft	Tp sec	Dir. deg az	-----------Water Levels------------ Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
2348	18.4	30.7	10	354	0.9	3.8	1.6	12.3	17.0
0150	8.9	14.8	11	16	0.0	2.5	0.8	12.4	14.9
0853	23.0	38.4	14	14	0.8	4.6	2.3	16.3	21.7
1953	15.1	25.2	11	11	0.6	3.5	1.4	12.7	16.8
1557	13.1	21.9	11	15	0.7	3.2	1.3	12.4	16.3
2057	25.9	43.3	14	11	0.5	5.0	2.5	16.5	22.0
1861	13.8	23.0	12	8	0.0	3.5	1.3	14.6	18.1
2762	30.5	51.0	16	11	0.9	5.4	3.2	18.2	24.5
0163	24.0	40.0	14	328	0.4	4.8	2.3	16.5	21.6
2563	36.1	60.3	16	343	1.4	5.6	3.8	19.2	26.2
2965	13.8	23.0	12	343	0.0	3.5	1.3	14.6	18.1
3367	41.3	69.0	16	5	2.4	5.7	4.4	20.8	28.8
2168	13.1	21.9	12	11	0.4	3.4	1.3	14.6	18.3
0571	13.8	23.0	12	16	0.1	3.5	1.3	14.6	18.2
0676	11.1	18.6	16	328	0.2	3.4	1.2	17.0	20.6
1977	18.7	31.2	12	9	0.5	4.1	1.7	14.3	18.9
2379	10.2	17.0	11	17	0.1	2.8	1.0	13.0	15.9
2187	23.0	38.4	14	353	0.4	4.7	2.3	16.4	21.5
0188	36.1	60.3	16	9	1.7	5.5	3.8	19.3	26.5
0289	19.7	32.9	12	353	0.4	4.2	1.8	14.5	19.1
0190	25.3	42.2	14	353	0.4	4.9	2.5	16.5	21.9
3190	17.1	28.5	14	20	0.4	4.1	1.8	16.9	21.4
2691	17.7	29.6	14	358	0.0	4.3	1.8	17.0	21.2
1592	24.6	41.1	14	11	0.7	4.8	2.4	16.4	21.9
3192	27.5	46.0	14	9	0.8	5.0	2.7	16.5	22.3
3594	9.5	15.9	16	6	-0.1	3.1	1.0	15.6	18.6
0597	35.7	59.7	14	9	1.2	5.5	3.5	17.4	24.1
2997	34.1	57.0	16	351	1.5	5.4	3.6	18.9	25.9
1367	42.3	70.7	16	3	2.1	5.8	4.4	21.0	28.9
4367	40.7	67.9	16	7	2.0	5.7	4.3	20.6	28.4
5163	34.8	58.1	16	1	1.7	5.4	3.7	18.9	26.1
6163	17.1	28.5	16	352	0.1	4.3	1.9	18.1	22.5

Table F57
Wave Parameters and Water Levels by Storm, Profile: Rota 57

Storm No.	----Wave Parameters---- Hs ft	H1 ft	Tp sec	Dir. deg az	-----------Water Levels------------ Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
2348	18.4	30.7	10	354	1.0	3.8	1.7	11.9	16.6
0150	8.9	14.8	11	16	0.0	2.5	0.9	12.4	15.0
0853	23.0	38.4	14	14	0.9	4.6	2.4	14.4	19.9
1953	15.1	25.2	11	11	0.6	3.5	1.5	12.3	16.4
1557	13.1	21.9	11	15	0.8	3.2	1.3	12.1	16.0
2057	25.9	43.3	14	11	0.6	4.9	2.7	14.9	20.4
1861	13.1	21.9	12	8	0.1	3.4	1.4	13.5	17.0
2762	30.5	51.0	16	11	1.1	5.3	3.3	17.9	24.3
0163	24.0	40.0	14	328	0.4	4.8	2.5	14.6	19.8
2563	36.1	60.3	16	343	1.5	5.6	3.9	20.3	27.4
2965	9.8	16.4	14	344	0.0	3.0	1.0	14.3	17.3
3367	41.3	69.0	16	5	2.4	5.6	4.5	22.1	30.2
2168	13.1	21.9	12	11	0.4	3.4	1.4	13.4	17.1
0571	13.1	21.9	12	17	0.1	3.4	1.4	13.5	17.0
0676	11.1	18.6	16	328	0.2	3.4	1.3	15.2	18.8
1977	18.7	31.2	12	9	0.6	4.1	1.9	13.1	17.8
2379	10.2	17.0	11	17	0.2	2.8	1.0	12.8	15.7
2187	23.0	38.4	14	353	0.5	4.7	2.4	14.5	19.6
0188	36.1	60.3	16	9	1.8	5.5	4.0	20.4	27.7
0289	19.7	32.9	12	353	0.4	4.2	1.9	13.2	17.9
0190	25.3	42.2	14	353	0.5	4.9	2.6	14.7	20.1
3190	16.0	26.8	14	21	0.4	4.0	1.8	14.8	19.1
2691	17.4	29.0	14	353	0.0	4.2	1.9	14.8	19.0
1592	24.6	41.1	14	11	0.8	4.8	2.6	14.6	20.2
3192	27.5	46.0	14	9	0.9	5.0	2.9	15.3	21.2
3594	9.5	15.9	16	6	-0.1	3.1	1.0	14.7	17.7
0597	35.7	59.7	14	9	1.4	5.4	3.7	17.7	24.5
2997	34.1	57.0	16	351	1.7	5.4	3.8	19.6	26.7
1367	42.3	70.7	16	3	2.2	5.8	4.6	22.3	30.3
4367	40.7	67.9	16	7	2.2	5.7	4.4	21.9	29.8
5163	34.8	58.1	16	1	1.8	5.4	3.8	19.9	27.1
6163	17.1	28.5	16	352	0.1	4.3	2.0	16.7	21.1

Table F61
Wave Parameters and Water Levels by Storm, Profile: Rota 61

Storm No.	----Wave Parameters---- Hs ft	H1 ft	Tp sec	Dir. deg az	-----------Water Levels------------ Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
2348	14.6	24.4	11	2	0.9	3.4	1.1	10.2	14.5
0150	8.4	14.0	11	16	0.0	2.4	0.5	7.8	10.2
0853	22.2	37.0	14	14	0.9	4.5	1.8	13.2	18.6
1953	14.8	24.7	11	11	0.6	3.5	1.0	10.2	14.3
1557	12.6	21.1	11	15	0.8	3.1	0.9	10.0	13.9
2057	24.4	40.8	14	11	0.6	4.8	1.9	13.2	18.6
1861	13.3	22.2	12	8	0.1	3.5	0.9	10.6	14.1
2762	29.5	49.3	16	11	1.1	5.2	2.5	15.9	22.3
0163	22.8	38.1	14	321	0.7	4.6	1.8	13.2	18.6
2563	36.8	61.4	16	343	1.6	5.6	3.0	16.8	24.0
2965	14.0	23.3	12	343	0.0	3.6	1.0	10.8	14.4
3367	40.5	67.7	16	5	2.5	5.6	3.4	17.8	25.9
2168	12.5	20.8	12	11	0.4	3.2	0.9	10.5	14.1
0571	15.3	25.5	12	15	0.2	3.7	1.1	11.1	15.0
0676	17.1	28.5	12	14	0.9	3.8	1.3	11.3	16.0
1977	18.2	30.4	12	9	0.6	4.0	1.3	11.4	16.0
2379	9.7	16.2	11	17	0.2	2.7	0.6	8.8	11.6
2187	22.0	36.7	14	347	0.5	4.6	1.7	13.4	18.5
0188	35.3	58.9	16	9	1.9	5.4	2.9	16.6	23.9
0289	18.6	31.0	12	1	0.6	4.1	1.4	11.4	16.0
0190	23.6	39.4	14	1	0.6	4.7	1.8	13.2	18.6
3190	17.9	29.9	14	18	0.5	4.2	1.4	13.1	17.7
2691	17.9	29.9	14	346	0.0	4.3	1.3	13.0	17.2
1592	23.5	39.2	14	12	0.9	4.7	1.9	13.1	18.7
3192	24.8	41.4	14	8	0.9	4.8	1.9	13.0	18.6
3594	9.3	15.6	16	6	-0.1	3.0	0.6	11.4	14.3
0597	35.1	58.6	14	9	1.5	5.4	2.7	14.1	21.0
2997	34.8	58.1	16	351	1.8	5.4	2.9	16.4	23.6
1367	42.0	70.1	16	3	2.3	5.7	3.5	17.9	25.9
4367	39.7	66.3	16	7	2.3	5.6	3.3	17.6	25.5
5163	34.3	57.3	16	1	1.8	5.4	2.9	16.3	23.5
6163	17.1	28.5	16	352	0.1	4.3	1.3	13.8	18.1

Table F65
Wave Parameters and Water Levels by Storm, Profile: Rota 65

Storm	----Wave	Parameters----			-----------Water	Levels-----------			
Storm No.	Hs ft	H1 ft	Tp sec	Dir. deg az	Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
2348	18.0	30.1	10	351	1.0	3.7	1.4	5.6	10.3
0150	7.8	13.1	11	11	0.0	2.2	0.6	2.6	4.9
0853	21.3	35.6	14	8	0.8	4.5	1.9	11.2	16.4
1953	14.4	24.1	11	6	0.6	3.4	1.2	5.6	9.6
1557	12.2	20.3	11	9	0.8	3.0	1.0	5.1	8.9
2057	23.6	39.4	14	5	0.6	4.8	2.1	11.1	16.4
1861	12.8	21.4	12	2	0.1	3.4	1.1	5.7	9.1
2762	28.6	47.7	16	6	1.0	5.2	2.7	12.2	18.5
0163	20.7	34.5	14	311	0.9	4.4	1.9	11.2	16.5
2563	37.4	62.5	16	339	1.6	5.6	3.5	13.8	21.0
2965	14.1	23.6	12	337	0.0	3.6	1.2	6.3	9.9
3367	39.7	66.3	16	0	2.5	5.6	3.8	14.5	22.5
2168	11.8	19.7	12	4	0.4	3.1	1.0	5.5	9.0
0571	14.8	24.7	12	9	0.1	3.7	1.2	6.6	10.4
0676	16.4	27.4	12	8	0.9	3.7	1.4	7.3	11.9
1977	17.7	29.6	12	3	0.6	4.0	1.5	7.2	11.8
2379	10.2	17.0	10	11	0.2	2.7	0.8	3.4	6.3
2187	22.3	37.3	14	343	0.5	4.7	2.0	11.1	16.2
0188	34.4	57.5	16	3	1.8	5.4	3.2	13.4	20.6
0289	19.0	31.8	12	352	0.6	4.1	1.6	7.6	12.2
0190	24.0	40.0	14	349	0.4	4.8	2.1	11.1	16.4
3190	17.1	28.5	14	12	0.4	4.1	1.6	10.3	14.8
2691	18.0	30.1	14	341	0.0	4.3	1.6	10.3	14.6
1592	22.0	36.7	14	9	0.8	4.6	2.0	11.1	16.4
3192	25.9	43.3	14	4	0.9	4.9	2.3	10.8	16.5
3594	9.2	15.3	16	358	-0.1	3.0	0.8	5.2	8.1
0597	34.4	57.5	14	5	1.4	5.4	3.0	11.6	18.4
2997	35.4	59.2	16	347	1.8	5.5	3.3	13.6	20.8
1367	41.7	69.6	16	358	2.3	5.7	3.9	15.0	23.0
4367	38.7	64.7	16	2	2.2	5.6	3.7	14.1	21.9
5163	33.8	56.4	16	356	1.8	5.4	3.2	13.3	20.5
6163	17.1	28.5	16	346	0.1	4.3	1.6	12.1	16.5

Table F69
Wave Parameters and Water Levels by Storm, Profile: Rota 69

Storm No.	Hs ft	H1 ft	Tp sec	Dir. deg az	Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
	----Wave Parameters----				-----------Water Levels------------				
2348	14.4	24.1	11	357	0.9	3.4	0.9	8.4	12.6
0150	7.8	13.1	11	11	0.0	2.2	0.4	4.8	7.1
0853	21.3	35.6	14	8	0.8	4.5	1.5	10.8	16.1
1953	14.4	24.1	11	6	0.5	3.4	0.9	8.2	12.2
1557	12.2	20.3	11	9	0.7	3.0	0.8	7.4	11.1
2057	24.3	40.5	14	5	0.4	4.8	1.6	11.3	16.5
1861	12.8	21.4	12	2	0.0	3.4	0.8	7.8	11.2
2762	28.6	47.7	16	6	0.9	5.2	2.1	14.5	20.6
0163	24.9	41.6	14	319	0.6	4.9	1.7	11.4	16.8
2563	37.4	62.5	16	339	1.6	5.6	2.8	14.8	22.0
2965	14.1	23.6	12	337	0.1	3.6	0.8	8.6	12.2
3367	39.7	66.3	16	0	2.4	5.6	3.0	15.4	23.4
2168	11.8	19.7	12	4	0.3	3.1	0.7	7.6	11.1
0571	14.8	24.7	12	9	0.1	3.7	0.9	8.8	12.6
0676	16.7	27.9	12	7	0.7	3.8	1.1	9.7	14.2
1977	17.7	29.6	12	3	0.4	4.0	1.1	9.9	14.3
2379	10.2	17.0	10	11	0.1	2.7	0.6	5.3	8.1
2187	22.3	37.3	14	343	0.5	4.7	1.5	10.9	16.0
0188	34.4	57.5	16	3	1.7	5.4	2.6	14.6	21.7
0289	19.0	31.8	12	352	0.5	4.1	1.2	9.8	14.5
0190	25.3	42.2	14	349	0.5	4.9	1.7	11.4	16.8
3190	17.1	28.5	14	12	0.4	4.1	1.1	10.3	14.8
2691	18.0	30.1	14	341	0.0	4.3	1.1	10.4	14.7
1592	23.0	38.4	14	5	0.7	4.7	1.6	11.1	16.5
3192	25.9	43.3	14	4	0.8	4.9	1.8	11.5	17.2
3594	9.2	15.3	16	358	-0.1	3.0	0.6	9.3	12.2
0597	34.4	57.5	14	5	1.2	5.4	2.3	12.4	19.0
2997	35.4	59.2	16	347	1.8	5.5	2.7	14.4	21.7
1367	41.7	69.6	16	358	2.3	5.7	3.1	15.7	23.7
4367	38.7	64.7	16	2	2.0	5.6	2.9	15.2	22.8
5163	33.8	56.4	16	356	1.9	5.3	2.6	14.6	21.8
6163	18.7	31.2	14	314	0.6	4.2	1.3	10.5	15.4

Table F73
Wave Parameters and Water Levels by Storm, Profile: Rota 73

Storm No.	Hs ft	H1 ft	Tp sec	Dir. deg az	Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
	----Wave Parameters----				-----------Water Levels------------				
2348	14.4	24.1	11	357	0.9	3.4	1.0	6.6	10.8
0150	7.8	13.1	11	11	-0.1	2.3	0.4	6.2	8.4
0853	21.3	35.6	14	8	0.5	4.5	1.5	7.4	12.4
1953	14.4	24.1	11	6	0.4	3.5	0.9	6.5	10.4
1557	12.2	20.3	11	9	0.6	3.1	0.8	6.3	9.9
2057	24.3	40.5	14	5	0.2	4.9	1.6	7.4	12.5
1861	12.8	21.4	12	2	-0.1	3.4	0.8	6.6	9.9
2762	28.6	47.7	16	6	0.4	5.3	2.1	7.0	12.8
0163	25.3	42.2	14	323	0.3	4.9	1.7	7.2	12.5
2563	37.7	62.9	16	339	1.2	5.7	2.8	6.3	13.3
2965	14.1	23.6	12	337	0.0	3.6	0.9	6.8	10.4
3367	39.7	66.3	16	0	2.3	5.6	3.0	6.4	14.2
2168	11.8	19.7	12	4	0.2	3.2	0.7	6.4	9.9
0571	14.8	24.7	12	9	0.0	3.7	0.9	7.0	10.7
0676	16.7	27.9	12	7	0.5	3.9	1.1	7.4	11.8
1977	17.7	29.6	12	3	0.3	4.0	1.1	7.5	11.8
2379	10.2	17.0	10	11	0.1	2.7	0.6	5.9	8.7
2187	22.6	37.7	14	343	0.3	4.7	1.5	7.4	12.4
0188	35.1	58.6	14	3	1.3	5.4	2.4	6.5	13.3
0289	19.0	31.8	12	352	0.5	4.1	1.2	7.4	12.1
0190	25.3	42.2	14	349	0.4	4.9	1.8	7.2	12.5
3190	17.1	28.5	14	12	0.2	4.1	1.1	7.8	12.2
2691	18.3	30.6	14	341	0.0	4.3	1.2	7.9	12.2
1592	23.0	38.4	14	5	0.4	4.7	1.6	7.3	12.4
3192	25.9	43.3	14	4	0.5	5.0	1.8	7.1	12.6
3594	9.2	15.3	16	358	-0.1	3.0	0.6	7.3	10.2
0597	34.4	57.5	14	3	0.9	5.5	2.3	6.6	12.9
2997	40.7	67.9	14	341	1.7	5.6	2.9	5.8	13.2
1367	41.7	69.6	16	358	2.2	5.7	3.2	6.5	14.4
4367	38.7	64.7	16	2	1.7	5.7	2.9	6.3	13.7
5163	33.8	56.4	16	356	1.8	5.4	2.7	6.0	13.2
6163	18.9	31.6	14	317	0.4	4.3	1.3	7.6	12.3

Table F77
Wave Parameters and Water Levels by Storm, Profile: Rota 77

	----Wave Parameters----				-----------Water Levels------------				
Storm No.	Hs ft	H1 ft	Tp sec	Dir. deg az	Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
2348	17.8	29.8	10	351	1.0	3.7	1.1	5.3	10.0
0150	7.2	12.0	11	10	0.0	2.0	0.4	4.2	6.2
0853	19.7	32.9	14	8	0.8	4.3	1.5	7.4	12.4
1953	12.8	21.4	11	6	0.6	3.2	0.9	5.7	9.4
1557	11.0	18.4	11	9	0.7	2.8	0.7	5.5	9.0
2057	22.9	38.2	14	5	0.5	4.7	1.6	7.8	12.9
1861	11.9	19.8	12	2	0.0	3.2	0.7	5.8	9.1
2762	26.7	44.6	16	6	0.9	5.1	2.1	9.5	15.5
0163	25.8	43.1	14	315	0.7	4.9	1.9	8.1	13.7
2563	38.6	64.5	16	339	1.5	5.7	3.0	11.6	18.9
2965	14.8	24.7	12	337	0.1	3.7	0.9	6.2	9.9
3367	38.1	63.6	16	0	2.5	5.5	3.0	12.0	19.9
2168	10.9	18.2	12	4	0.3	3.0	0.7	5.7	9.0
0571	12.9	21.6	12	9	0.1	3.4	0.8	6.0	9.5
0676	15.3	25.6	12	7	0.7	3.6	1.1	6.2	10.6
1977	16.6	27.7	12	3	0.5	3.8	1.1	6.4	10.7
2379	9.2	15.3	10	10	0.2	2.4	0.6	4.8	7.4
2187	23.1	38.6	14	343	0.4	4.7	1.6	7.8	13.0
0188	31.9	53.3	16	3	1.8	5.2	2.6	10.6	17.6
0289	18.6	31.0	12	352	0.6	4.1	1.3	6.5	11.1
0190	25.0	41.8	14	349	0.5	4.9	1.8	8.0	13.4
3190	19.7	32.9	12	4	0.3	4.3	1.3	6.5	11.1
2691	18.6	31.1	14	341	0.0	4.4	1.3	7.1	11.5
1592	20.9	34.9	14	5	0.7	4.4	1.5	7.6	12.7
3192	24.6	41.0	14	4	0.8	4.8	1.8	8.0	13.6
3594	10.5	17.5	11	348	0.0	2.9	0.6	5.4	8.3
0597	32.2	53.7	14	3	1.2	5.2	2.3	8.7	15.2
2997	40.7	67.9	14	341	2.2	5.5	3.0	10.1	17.8
1367	40.5	67.7	16	358	2.3	5.6	3.2	12.4	20.4
4367	37.1	62.0	16	2	2.1	5.5	2.9	11.6	19.2
5163	32.9	54.9	16	356	2.0	5.3	2.7	10.7	17.9
6163	21.3	35.6	14	313	0.6	4.5	1.6	7.6	12.7

Table F81
Wave Parameters and Water Levels by Storm, Profile: Rota 81

Storm No.	Hs ft	H1 ft	Tp sec	Dir. deg az	Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
	----Wave Parameters----				-----------Water Levels------------				
2348	13.8	23.0	11	353	0.9	3.2	1.2	9.2	13.4
0150	6.9	11.5	11	3	0.0	2.0	0.5	7.6	9.6
0853	19.0	31.8	14	1	0.8	4.2	1.7	11.6	16.6
1953	12.2	20.3	11	355	0.6	3.0	1.0	9.4	13.1
1557	10.5	17.5	11	2	0.7	2.7	0.9	9.3	12.7
2057	22.3	37.3	14	359	0.5	4.6	2.0	11.6	16.7
1861	11.5	19.2	12	354	0.0	3.2	0.9	9.9	13.1
2762	25.9	43.3	16	359	1.1	5.0	2.5	14.1	20.1
0163	27.5	46.0	14	316	0.6	5.1	2.3	12.2	17.8
2563	39.0	65.2	16	334	1.7	5.7	3.6	15.9	23.4
2965	15.1	25.2	12	332	0.1	3.7	1.2	10.2	14.0
3367	37.4	62.5	16	355	2.5	5.4	3.5	15.9	23.8
2168	10.5	17.5	12	357	0.4	2.9	0.9	9.7	12.9
0571	12.2	20.3	12	356	0.1	3.2	1.0	10.0	13.4
0676	13.5	22.5	16	313	0.2	3.8	1.2	11.8	15.7
1977	16.0	26.8	12	357	0.5	3.8	1.4	10.0	14.3
2379	8.9	14.8	10	3	0.2	2.3	0.7	8.2	10.8
2187	23.3	38.9	14	338	0.5	4.7	2.0	11.5	16.7
0188	30.8	51.5	16	355	1.9	5.2	2.9	14.6	21.7
0289	17.4	29.0	12	350	0.6	3.9	1.5	9.9	14.4
0190	24.9	41.6	14	344	0.6	4.9	2.1	11.7	17.1
3190	14.1	23.6	14	0	0.4	3.7	1.3	11.1	15.2
2691	18.7	31.2	14	346	0.0	4.4	1.6	11.5	15.9
1592	20.0	33.4	14	355	0.8	4.3	1.8	11.6	16.7
3192	24.0	40.0	14	358	0.9	4.7	2.1	11.5	17.1
3594	10.5	17.5	11	342	0.0	2.9	0.8	9.3	12.2
0597	31.2	52.1	14	356	1.4	5.2	2.7	12.7	19.2
2997	40.7	67.9	14	338	2.4	5.5	3.6	14.8	22.6
1367	40.0	66.8	16	353	2.4	5.6	3.8	16.2	24.2
4367	36.4	60.8	16	356	2.2	5.4	3.4	15.7	23.4
5163	32.5	54.2	16	351	2.0	5.2	3.0	15.0	22.3
6163	18.7	31.2	16	342	0.1	4.5	1.7	13.0	17.6

Table F85
Wave Parameters and Water Levels by Storm, Profile: Rota 85

Storm No.	----Wave Parameters---- Hs ft	H1 ft	Tp sec	Dir. deg az	-----------Water Levels------------ Surge ft	Ponding ft	Setup ft	Runup ft	Total ft
2348	13.8	23.0	11	353	0.9	3.2	1.1	11.6	15.7
0150	6.9	11.5	11	3	0.0	2.0	0.4	7.9	9.9
0853	19.0	31.8	14	1	0.8	4.2	1.6	21.2	26.2
1953	12.2	20.3	11	355	0.6	3.1	0.9	11.1	14.8
1557	10.5	17.5	11	2	0.7	2.7	0.8	10.5	13.9
2057	21.7	36.2	14	359	0.5	4.6	1.8	21.4	26.5
1861	11.5	19.2	12	354	0.0	3.2	0.8	11.3	14.5
2762	25.9	43.3	16	359	1.0	5.0	2.3	26.3	32.3
0163	22.3	37.3	14	335	0.3	4.7	1.8	21.4	26.3
2563	39.0	65.2	16	334	1.7	5.7	3.3	27.2	34.6
2965	15.1	25.2	12	332	0.1	3.7	1.1	13.6	17.4
3367	37.4	62.5	16	355	2.5	5.4	3.3	27.1	35.0
2168	10.5	17.5	12	357	0.4	2.9	0.8	10.9	14.2
0571	12.2	20.3	12	356	0.1	3.2	0.9	11.7	15.1
0676	13.5	22.5	16	313	0.2	3.8	1.1	18.1	22.0
1977	16.0	26.8	12	357	0.5	3.8	1.2	14.7	19.0
2379	8.9	14.8	10	3	0.2	2.4	0.6	8.8	11.4
2187	22.0	36.7	14	334	0.4	4.6	1.8	21.4	26.4
0188	25.6	42.7	16	358	1.4	4.9	2.3	26.3	32.6
0289	17.4	29.0	12	350	0.6	3.9	1.3	15.0	19.5
0190	22.0	36.7	14	350	0.7	4.6	1.8	21.3	26.5
3190	14.1	23.6	14	0	0.4	3.7	1.1	17.1	21.2
2691	18.7	31.2	14	346	0.0	4.4	1.5	20.8	25.1
1592	20.0	33.4	14	355	0.8	4.3	1.7	21.4	26.5
3192	22.3	37.3	14	356	0.9	4.6	1.9	21.2	26.6
3594	10.5	17.5	11	342	0.0	2.9	0.7	10.1	13.0
0597	31.2	52.1	14	356	1.4	5.2	2.5	21.5	28.0
2997	40.7	67.9	14	338	2.4	5.5	3.4	24.7	32.6
1367	40.0	66.8	16	353	2.4	5.6	3.5	27.9	35.8
4367	36.4	60.8	16	356	2.2	5.4	3.2	26.6	34.3
5163	35.4	59.2	16	348	1.2	5.6	3.0	25.5	32.4
6163	18.7	31.2	16	342	0.1	4.5	1.5	23.8	28.4

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14. ABSTRACT

A set of typhoon-induced stage-frequency relationships was developed for inhabited coasts of the island of Rota, Commonwealth of the Northern Mariana Islands. The objective was to assist the Honolulu District in estimating extreme maximum inundation levels and maximum still-water levels with return period of up to 500 years. Calculations of surge, wind and pressure field, and wave characteristics were performed for 28 historical storms and four hypothetical variations of historical storms through application of numerical models. Wave-induced ponding, setup, and runup were calculated at 87 profile locations specified by the Honolulu District. The Empirical Simulation Technique was applied to calculate stage-frequency relationships based on historical storm parameters and calculated response to the storms. These relationships were calculated from the maximum total water levels computed for each storm (including storm surge, ponding, and runup) and from the maximum still-water levels for each storm (including storm surge, ponding, and wave setup). The methodology was calibrated to observations so that stage-frequency values for maximum total water level are expected to represent maximum debris line inundation levels.

15. SUBJECT TERMS

	Finite element modeling	Typhoon modeling	Wind wave modeling
Coastal flooding	Fringing reef	Wave runup	
Empirical Simulation	Storm surge	Wave setup	

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